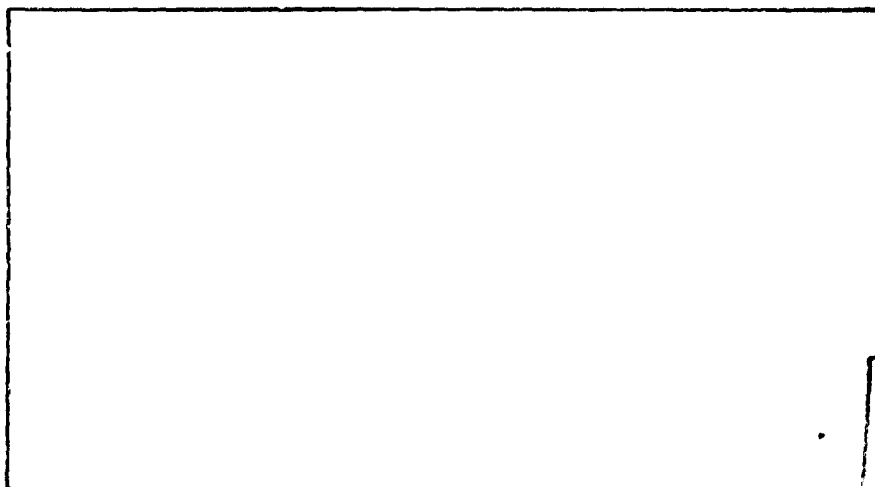


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12. ABSTRACT

Particulate concentration, particle size distribution, and mercury and lead concentrations in atmospheric particulates on Wright-Patterson Air Force Base (WPAFB), Ohio, were determined. Samples were taken from three locations on WPAFB using an Anderson hi-volume sampler head mounted on a Staplex hi-volume sampler. Particulates were fractionated by the sampler head as follows: greater than 7.0, 3.3 to 7.0, 2.0 to 3.3, 1.1 to 2.0, and less than 1.1 microns in equivalent aerodynamic diameter.

The distribution of the particulate concentrations was analyzed using the Reverse Arrangements test to establish randomness, the Kolmogorov-Smirnov test to compare ten proposed probability density functions with the data collected, and the Likelihood Ratio test to isolate the function best describing the data. The mean particulate concentration was 85.1 ug/m^3 , with a variance of 1048.2.

Particulates under 1.1 microns composed an average of 31.3 per cent of the total weight, those from 1.1 to 7.0 microns made up 31.9 per cent, and those over 7.0 microns composed 36.8 per cent of the sample.

The average lead concentration during a 24-hour sampling period was 1.25 ug/m^3 ; 50.9 per cent of the lead was found in particulates under 1.1 microns. Mercury concentrations in particulates averaged 6.9 ng/m^3 , however, due to inconsistencies in the analytical method no correlation could be established between mercury concentration and particle size.

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THESIS

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Dennis L. Brown
Captain USAF



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SIZE DISTRIBUTION, MERCURY/LEAD
CONCENTRATIONS, AND STOCHASTIC ANALYSIS
OF SUSPENDED PARTICULATES IN AMBIENT AIR

THESIS

Presented to the Faculty of the School of Engineering of
the Air Force Institute of Technology
Air University

In Partial Fulfillment of the
Requirements for the Degree of
Master of Science

by

Dennis L. Brown, B.S.C.E.
Captain USAF

Graduate Aerospace Facilities

June 1972

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Preface

In this study, I have attempted to answer a few of the many questions which arise when considering atmospheric pollution. It was my purpose to establish the levels of lead and mercury contamination, particulate concentrations, and the size distribution of particulates. Others more qualified in the medical field must take this information and judge the affect on the human body.

I would like to express my thanks to Captain Thomas Eastler, my thesis advisor, for his constant support and encouragement during this study. Also special thanks go to Professor T. L. Regulinski for his patient instruction and advice concerning stochastic processes, and the use of his computer program for analysis of particulate concentrations. The remainder of my faculty committee, Major Stewart Johnson and Dr. Ernest Dorko, have been very helpful in giving technical advice and suggestions in preparing this report.

This project was funded by the Civil Engineering Division, Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico. Not only was the financial support appreciated, but suggestions from Captain Dennis Naugle, project monitor, proved quite valuable in the course of the study. Dr. Charles Ritter, University of Dayton, gave extensive assistance in establishing techniques for mercury analysis. Mr. Millard Wolfe and the men of AFIT Shops constructed the sampling shelter and the adapter to mount the sampler head on the sampler.

Dennis L. Brown

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Abstract

Particulate concentration, particle size distribution, and mercury and lead concentrations in atmospheric particulates on Wright-Patterson Air Force Base (WPAFB), Ohio, were determined. Samples were taken from three locations on WPAFB using an Anderson hi-volume sampling head mounted on a Staplex hi-volume sampler. Particulates were fractionated by the sampler head into five size groups as follows: greater than 7.0, 3.3 to 7.0, 2.0 to 3.3, 1.1 to 2.0, and less than 1.1 microns in equivalent aerodynamic diameter.

The distribution of the particulate concentrations was analyzed using the Reverse Arrangements test to establish randomness, the Kolmogorov-Smirnov test to compare ten proposed probability density functions with the data collected, and the Likelihood Ratio test to isolate the function best describing the data. The Lognormal density function was found to best describe the data. The mean particulate concentration was 85.1 ug/m^3 , with a variance of 1048.2.

Particulates under 1.1 microns composed an average of 31.3 per cent of the total weight, those from 1.1 to 7.0 microns made up 31.9 per cent, and those over 7.0 microns composed 36.8 per cent of the sample.

The average lead concentration during a 24-hour sampling period was 1.25 ug/m^3 ; 50.9 per cent of the lead was found in particulates under 1.1 microns. Mercury concentrations in

particulates averaged 6.9 ng/m^3 , however, due to inconsistencies in the analytical method no correlation could be established between mercury concentration and particle size.

SIZE DISTRIBUTION, MERCURY, LEAD
CONCENTRATIONS, AND STOCHASTIC ANALYSIS
OF SUSPENDED PARTICULATES IN AMBIENT AIR

I. Introduction

The importance of preserving the quality of our atmosphere has been highly publicized in recent years, and the study of "air pollution" has increased vastly during that period. In considering the term "air pollution" one must assume that there exists a normal or "natural" background level of contaminants in the atmosphere, and that levels of contaminants greater than this background level have been introduced into the atmosphere by man, thus producing a polluted condition.

The Air Force has had a program underway to reduce air pollutant emissions from fixed facilities since Fiscal Year 1968. The primary emphasis of this program is converting heating plants from coal to natural gas or coal to oil with natural gas backup (Ref. 8). In view of the current emphasis placed on defining and solving environmental problems, this thesis was chosen to study certain aspects of air pollution at Wright-Patterson AFB (WPAFB), Ohio.

The purpose of this study is threefold: (1) determination of the size distribution of suspended particulates in ambient air; particles will be classified into one of five particle size groups, (2) determination of mercury and lead

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concentrations in each of the five particle size groups, and (3) isolation of the probability density function which best describes the data collected on suspended particulate concentrations in ambient air.

Particle Size Distribution

Because of the nature of the human respiratory system, a particle of given aerodynamic diameter can penetrate the system to a certain point before it is removed from the airstream (Fig. 3). Particles greater than 7 microns will likely be trapped in the nasal passages, particles from 3.3 to 7 microns can reach the trachea and primary bronchi, 2.0 to 3.3 micron particles reach the secondary bronchi, those from 1.1 to 2.0 microns penetrate to the terminal bronchi, and the particles less than 1.1 microns reach the alveoli of the lungs (Ref. 2). Thus the particles of smaller aerodynamic diameter present more danger to the human body than the larger particles. In this portion of the thesis the distribution of the suspended particulates in the previously mentioned fractionations is determined.

Trace Element Determination

Mercury. Coal is the present energy source for the heating plants on WPAFB. A study conducted by the Geological Survey of Illinois showed a mean mercury concentration in ten Illinois coal seams to be 180×10^{-9} g/g (Ref. 22). Another study which included coal samples from several midwestern and eastern states indicated a mean value of 3300×10^{-9} g/g of mercury in the samples analyzed. Using a conservative figure

for their study of 1000×10^{-9} g/g, an estimated 3000 tons of mercury per year are released into the earth's environment as coal is burned (Ref. 10).

Because of this evidence of mercury content in coal, the first element chosen for study was mercury. Because the toxicity is dependent on the amount of the element entering the various stages of the respiratory system, the mercury concentration of particles in the previously mentioned five size groups is considered.

Lead. An estimated 180,000 tons of lead per year are emitted into the air of the United States from the tailpipes of automobiles, trucks, and buses (Ref. 4). A report prepared for the Environmental Protection Agency (EPA) by a committee of the National Research Council found that "the level of lead in ambient air poses a significant threat in infants and small children." The report goes on to state that "the air over the largest American cities has a concentration of lead 20 times greater than the air over sparsely populated areas of the country and 2000 times greater than the air over the mid-Pacific Ocean" (Ref. 4). These statements and figures point out the importance of determining the lead concentrations on Air Force bases, especially those with large amounts of proximal vehicular traffic such as WPAFB. Thus, the second element chosen for this study was lead. Like mercury, the lead concentrations of particles in five size groups is considered.

Stochastic Analysis

In the continuing quest to predict and manage future air pollution situations, many attempts have been made to construct mathematical models of environments where air pollution is or may become a problem. These models are of two types: (1) deterministic models, and (2) stochastic models.

Deterministic models are constructed by determining mathematical relationships between the many variables in an air pollution system. Although some deterministic models have proven to be effective, they require huge amounts of data, and many have not proven to be reliable (Ref. 23).

Stochastic models have ranged in complexity from those using historical trends of monthly dustfall to sophisticated nonlinear prediction techniques (Ref. 23). Stochastic models are based on the random variation of phenomena generated by a complex system of sources and atmosphere continually solving its own problem of action and interaction.

A stochastic model has been developed in this thesis for the suspended particulate concentration at WPAFB by isolating the probability density function which best describes the data collected at three sampling locations on the base.

II. Equipment and Procedures

Equipment

Several items of specialized equipment were used in the course of this study. This equipment will be discussed briefly in this chapter, and described in detail in Appendix B.

An Anderson hi-volume sampler head manufactured by 2000 Inc. was used to fractionate the particulates aerodynamically into four size groups, greater than 7.0, 3.3 to 7.0, 2.0 to 3.3, 1.1 to 2.0 microns, and particles under 1.1 microns in diameter were collected on a backup filter. The sampler head was mounted on a Staplex hi-volume sampler. Since the sampler head was designed to operate at 0.566 cubic meters per minute (20 cubic feet per minute), the sampler was electrically connected through a variable voltage transformer which was adjusted to provide the specified flow rate. The sampling unit was mounted in a locally manufactured shelter (Fig. 12).

A Perkin-Elmer Model 403 atomic absorption spectrophotometer was used to perform the lead and mercury analysis. A Model 403 burner control was used for flame absorption in the lead analysis, and a flameless technique was used to analyze for mercury.

A CDC 6600 computer was used to compute and plot least-squares curve fits of all calibration curves in the atomic absorption work, and to conduct the stochastic analysis of particulate concentrations.

Procedures

The following procedures were used in the collection of particulate samples and in their subsequent analysis. An attempt was made to conform to existing procedures established by the American Society for Testing and Materials (ASTM) in Ref. 3, and the EPA in Ref. 18 on hi-volume air sampling, and procedures contained in Analytical Methods for Atomic Absorption Spectrophotometry (Ref. 1) were followed where applicable in atomic absorption work.

Selection of Sampling Sites. The three locations on WPAFB used in sample collection are shown in Fig. 1. Each site was chosen because it represented a different environment than the others, and combined, they formed a representative cross-section of the base. No attempt will be made to analyze the data from the sites on an individual basis; rather the combined data will be considered to represent the base as a whole.

Site I was chosen in a seemingly remote area of the base. During the summer months the area is used for recreation, but during the winter there is very little activity in the area. The site was, however, in the "no-build zone" near the southwest end of runway 05-23 at Patterson Field. In addition to being directly below the most active departure flight path at Patterson Field, the site was located approximately 800 meters downwind from one of the base's coal-fired heating plants.

Site II was selected because of its proximity to a coal-fired heating plant. The area showed evidence of heavy

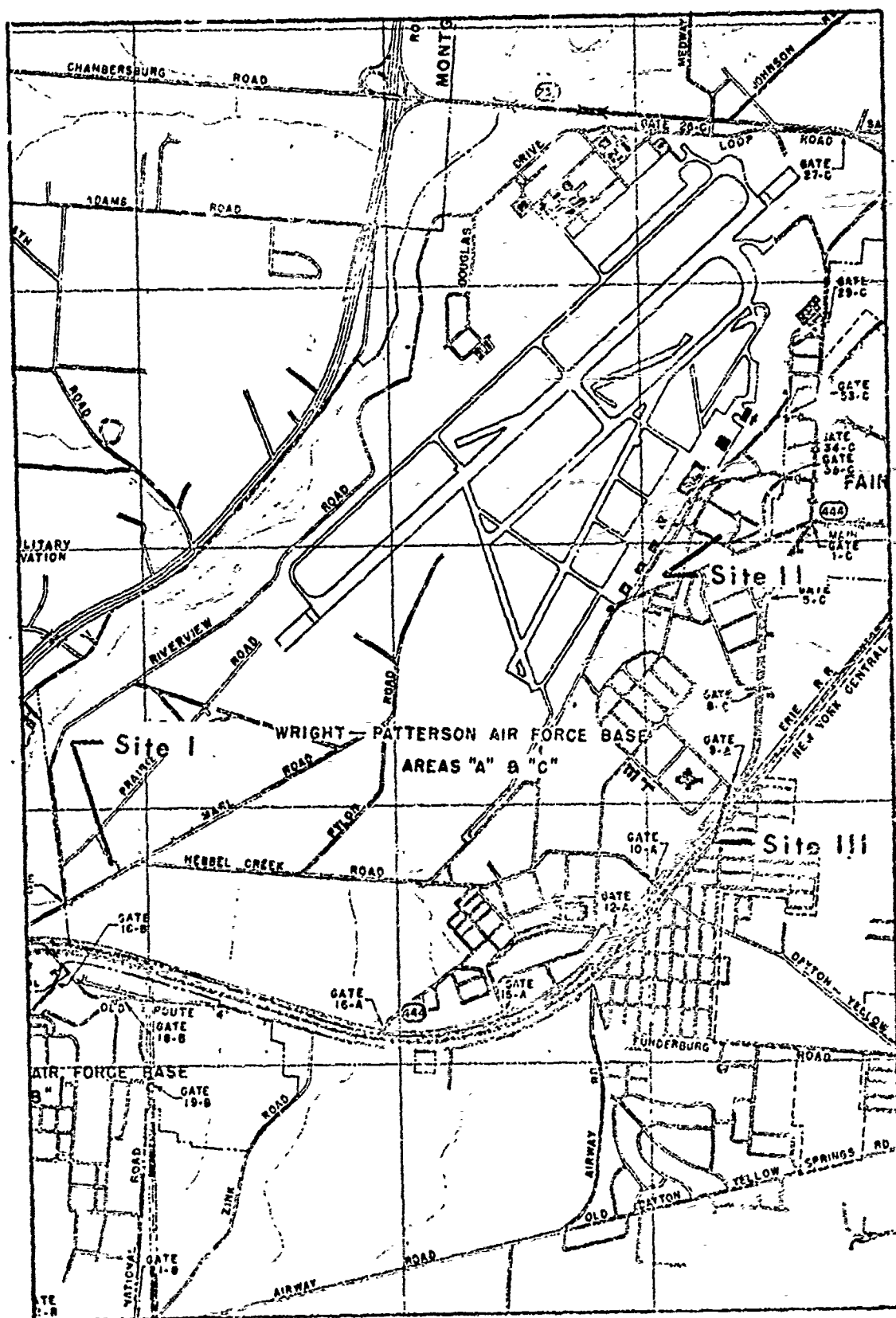


Fig. 1. Sampling Site Locations

dustfall from the stacks, and was chosen mainly to gain information on mercury levels near the plant. The site was also within two blocks of the Base Exchange and Commissary complex.

Site III was near Gate 9-A. This location experienced heavy automotive traffic since it served the Base Hospital, Officers' housing area on Patterson Field, the BOQ/VOQ complex, and the Officers' Club. Although this entrance did not experience the peak flow in the early morning and late afternoon that some other gates did, it was open 24 hours each day, 7 days per week. This site was also of interest because of its proximity to the Hospital.

Sample Collection. The first step in the collection of samples was to dry the clean collection papers and backup filter for a period of 24 hours in a desiccator. The papers and filter were then removed from the desiccator and immediately weighed to the nearest 0.0001 gram. The collection papers were next installed in the sampler head (Fig. 6) as it was assembled, after which the head and backup filter were transported to the sampling location. The backup filter was secured in place on the Staplex sampler by the adapter plate, and the sampler head was then mounted on the adapter (Fig. 10).

The sampler was then started, and the flow rate adjusted using the manometer to check the equivalent pressure drop in the head for a flow rate of 0.566 cubic meters per minute (cmm). The variable voltage transformer was adjusted to change the flow rate as necessary. Several bulk samples were also taken using only the backup filter to collect the particulates. In this case the filter was mounted as before,

but the sampler head was not used. The flow rate was measured using the flowmeter mounted on the base of the Staplex sampler, and was adjusted to 0.708 cmm at the start of the sampling period using the variable voltage transformer. The flowmeter was calibrated by comparing its measurements with flow rates determined by use of a manometer measuring pressure drops within the calibrated sampler head. The sampler was then operated for 24 hours to obtain the sample.

At the end of the 24-hour period the flow rate was checked and noted, and the sampler was turned off. Because of the head design, a constant flow rate was maintained throughout the period of its use; a maximum of 0.057 cmm drop was noted in the bulk samples. When the flow rate varied during the sampling period, the beginning and ending flow rates were averaged and multiplied by the sample time to determine the volume of air sampled. The sampler head and the backup filter were then removed and taken to the laboratory. There the collection paper was removed from the head and placed, along with the backup filter, in the desiccator to dry for 24 hours.

Following the 24-hour drying period the paper was weighed, again to the nearest 0.0001 gram. The difference in the initial and final weighings was the weight of the particulates collected on that paper or filter. The papers and filter of each 24-hour sample were then placed in a clean 24.1 by 30.5-cm envelope and stored until chemical analysis was performed.

Sample Preparation. In conducting the mercury and lead analysis it was assumed that the particulates were evenly

distributed on the collection papers and filters. All glassware was rinsed with a dilute nitric acid solution and distilled-deionized water before use to remove any mercury or lead contamination.

One-fourth of the collection paper and backup filter were used for mercury analysis, and one-fourth for lead analysis. The quarters were cut with a razor blade into small pieces, approximately 1 by 1-cm. These pieces were then placed in a clean 100 ml beaker. The particulates were extracted by adding 30 ml of 50% nitric acid to each beaker and allowing the collection papers and filters to digest for 24 hours. The solid material was then removed from the solution by filtering through a Buchner funnel. The extraction and filtering techniques were checked by spiking a collection paper with a known amount of lead and using these techniques to prepare the sample for analysis. Results of the analysis showed that all the lead had been placed into solution and was separated from the solid material by filtering. Similar tests were performed on clean collection paper and filters to determine the amount of mercury and lead present in the paper. Negligible amounts of mercury and no lead were found.

Atomic Absorption Technique.

Mercury Analysis. The mercury concentrations in the 100 ml sample were anticipated to be on the order of 10 parts per billion (ppb) and below. To measure these extremely low concentrations, a flameless technique was used which detected concentrations as low as 1 ppb.

To conduct atomic absorption analysis standard solutions

of the element under investigation must be prepared. Mercuric chloride reagent was dried in an oven at 100° C for 24 hours, and then allowed to cool under desiccation. 1.3535 grams of the reagent were dissolved in 50 ml of concentrated nitric acid, and then diluted with distilled-deionized water to provide a one part-per-million (ppm) solution which is stable for approximately one month. Aliquots of this one ppm solution were then diluted to provide the standards used to establish the calibration curves.

A reductant solution was prepared which served to reduce the mercury to its elemental state. The reductant consisted of 5 grams sodium chloride, 10 grams hydroxylamine hydrochloride, and 20 grams stannous chloride. These reagents were added to a solution of 100 ml concentrated sulfuric acid and 500 ml of distilled-deionized water. The mixture was then diluted to 1000 ml, a magnetic stirring rod added, and placed on a magnetic stirrer to mix for one hour. The mixture was finally filtered into containers and stored for future use.

After the samples had been filtered to remove the solids, the solution was diluted to 100 ml. All standards used in the calibration were 100 ml of known concentrations. The samples and standards were placed in 250 ml erlenmeyer flasks. Standards included a blank (distilled-deionized water), 2.5, 5.0, 10.0, and 15.0 ppb. The erlenmeyer flasks were then placed in an ice bath to inhibit mercury vaporization and 10 ml of concentrated sulfuric acid, 5 ml of concentrated nitric acid, and 5 ml 5% w/v potassium permanganate solution were

added. The flasks were then removed from the ice bath and allowed to stand at room temperature for 10-15 minutes.

The samples and standards were then ready for analysis. The first set of standards was analyzed, followed by analysis of the samples after which a second set of reference standards was analyzed. To analyze a standard or sample a stirring bar is placed in the flask, and the flask placed on a magnetic stirrer as shown in Fig. 2. A stopper is then placed on the flask with inlet and outlet air lines and a hypodermic needle inserted. Fifty ml of reductant is added through the hypodermic needle using a syringe. A constant air flow of 0.0566 cubic meters per hour flows through the line to carry the volatilized mercury out of the flask, through a magnesium perchlorate filter which removes any water vapor, and into the absorption cell. The atomic absorption spectrophotometer then determines the per cent absorption by comparing the intensity of a light beam emitted at the characteristic wavelength of mercury which bypasses the absorption cell with a beam at the same wavelength which passes through the cell. The percentage of absorption is then converted to absorbance units and displayed on the digital readout. Because of the standardized conditions, the peak absorbance reading was used to determine the corresponding sample concentrations.

The data obtained from the standards was used as input to a computer program, and a least-squares curve fit was determined. Previous studies have indicated a linear relationship between absorbance and concentration in the range under consideration (Ref. 21). Using this curve, the computer

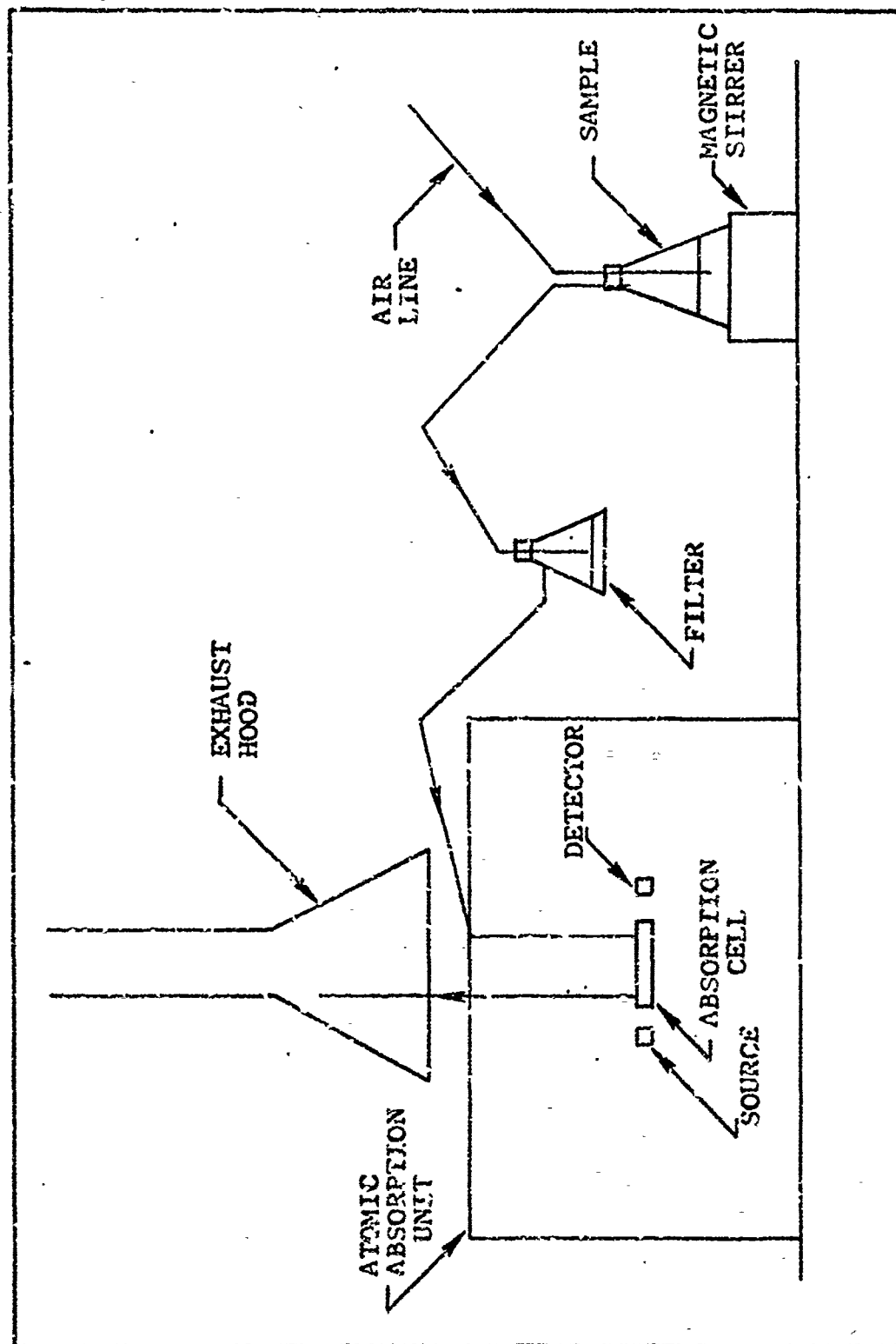


Fig. 2. Schematic Diagram of Mercury Analysis Equipment

converted the absorbance readings obtained for the samples to sample concentrations, from which the ambient air concentration was calculated using Eq (1).

ambient air concentration =

$$\frac{(\text{sample concentration}) (\text{Volume of the sample})}{(\text{volume of air sampled})} \quad (i)$$

Lead Analysis. Lead concentrations were expected to be high enough to use the standard flame absorption technique in the analysis. The standard lead solution was prepared by diluting 1.5935 grams of lead nitrate in a 2% nitric acid solution to 1000 ml. This solution contained one ppt lead. Aliquots were taken and diluted to 100 ml to obtain standards of 0.5, 1.0, 2.5, 5.0, 7.5, 10.0, and 15.0 ppm. After the samples were filtered to remove the solids, the solution was diluted to 50 ml. The samples and standards were then ready for analysis.

An air-acetylene flame was used to reduce the lead in the solution to its elemental state while in the absorption path. The air and acetylene flow rate and pressure were adjusted to maximize the absorbance using procedures from Ref. 1. The burner was adjusted in much the same manner. The aspiration rate was then adjusted, again to maximize the absorbance of a known standard.

A set of standards was analyzed to determine the calibration curve for lead, and the absorbance of the samples was then determined by aspirating the solution into the flame. As in the mercury analysis the data were fed into the computer

where the least-squares curve fit of the calibration curve was determined, and the sample concentration and ambient air concentration were calculated. The ambient air concentration was again calculated using Eq (1),

III. Stochastic Analysis

The development of air pollution modeling is a relatively new field of study, and it is critically important if we are to predict and control the amount of air pollution in the future. The approach taken in this study is similar to that used in reliability and maintainability studies (Refs. 19 and 20). If data collected is shown to be random, the use of a stochastic model is indicated, and deterministic models are inapplicable. A stochastic model is valid only if the randomness of the data can be shown. The assumption that the data on particulate concentrations would be random and would therefore be modeled stochastically was made at the beginning of this study, and was confirmed when data collection was complete. When randomness was established, a mathematical function was sought which adequately described the probability distribution of the particulate concentration random variable. Since the data on particulate concentration is in the continuous realm, the probability density function (pdf) is the function desired. When the governing pdf was isolated, the characteristics of the particulate concentration, such as expectation and variance were determined, and the model could then be used to predict the behavior of particulate concentrations.

To accomplish the analysis described above a computer program written by Prof. T. L. Regulinski of the Electrical Engineering Faculty (AFIT) was used. A flow diagram of the

program is included in Appendix C.

The hypothesis of randomness was tested by using the Reverse Arrangements Test (Ref. 5). This test considers the sequence of data (x_i) in the order collected. The number of times that $x_i > x_j$ for $i < j$ is then counted. Each such inequality is called a reverse arrangement. The total number of reverse arrangements for $i = 1, 2, 3, \dots, N$ is denoted as A . In the sequence of N observations ($N > 20$) the number of reverse arrangements, $A(k)$, is also a random variable. It is normally distributed with a mean

$$\mu_A = N(N-1)/4 \quad (2)$$

and variance

$$\sigma^2 = N(2N+5)(N-1)/72 \quad (3)$$

Acceptance of the hypothesis of randomness is given by the region

$$A_{N; 1-\frac{\alpha}{2}} \leq A \leq A_{N; \frac{\alpha}{2}} \quad (4)$$

where the values of the different significance levels can be computed from Eqs (2) and (3) using normal probability distribution tables.

When randomness was established by the reverse arrangements test, the probability density function which described the data is sought. The Kolmogorov-Smirnov (K-S) goodness of fit test (Ref. 14) was used to compare the cumulative distribution of the data collected to ten theoretical distribution functions. The density functions used in the test were

the Smallest Extreme Value, Largest Extreme Value, Uniform, Exponential, Log Normal (Natural Log), Normal, Gamma (Three Parameter), Weibull (Three Parameter), Beta, and Beta*. The Beta and Beta* are identical except in the method of estimating the parameters. The mathematical expressions for each of the functions are included in Appendix D, and a description of the parameter likelihood estimates is summarized in Ref. 19.

The K-S test compares the cumulative frequency distribution function, $F_0(x)$, of the theoretical density function to the observed cumulative step-function of the sample, $S_n(x)$. The test was set up by determining the maximum difference

$$D = \max |F_0(x) - S_n(x)| \quad (5)$$

over all n data points. The theoretical distribution passes the K-S test at the 0.20 level of significance if $D < d$ where d is the critical value of the K-S statistic and can be found in tables of Ref. 14.

The K-S test will either accept or reject the hypothesis that a given theoretical density function describes the data at a stated level of significance. If more than one of the proposed density functions were accepted, the Likelihood Ratio test (Refs. 20 and 24) was used to isolate the function which best described the data. The test is defined by

$$L(X) = f_1(X|H_1) / f_0(X|H_0) \quad (6)$$

where

$$f_j(X|H_j) = \prod_{i=1}^n f_j(x_i|H_j) \quad (7)$$

The null hypothesis

$$H_0 : \text{Distribution is } F_0(x) \quad (8)$$

was tested against

$$H_1 : \text{Distribution is } F_1(x) \quad (9)$$

The threshold of the test was taken to be unity for this test based on rational given in Ref. 20. All distribution functions passing the K-S test were tested against each other; thus leading to one hypothesis being selected over the others.

IV. Results

Particle Size Distribution

The data collected from the 56 fractionated samples are summarized in Appendix A. Additional information on the distribution of the data within each size group is obtained in the results of the stochastic analysis (Table IV).

It is of interest to note that an average of 36.8 per cent of the total particulates were over 7.0 microns in diameter; particles of this size are generally filtered by the respiratory system before they have a chance to enter the lungs. On the other extreme, however, 31.3 per cent of the particulates were less than 1.1 microns in diameter; particles of this diameter can penetrate deeply into the human respiratory system. Particles less than 1.1 microns have a very slow settling velocity, 1.0 micron particles settle at 3.49×10^{-3} cm/sec, and many stay suspended indefinitely unless "washed" from the atmosphere by precipitation. The remaining 31.9 per cent of the particulates penetrate the respiratory system to varying degrees, but are not nearly as critical to human health as the particles under 1.1 microns. Fig. 3 shows the depth that various sized particles penetrate the human respiratory system.

Mercury Concentrations

Data obtained from the mercury analysis of the particulates indicate an average concentration of 6.9×10^{-9} grams

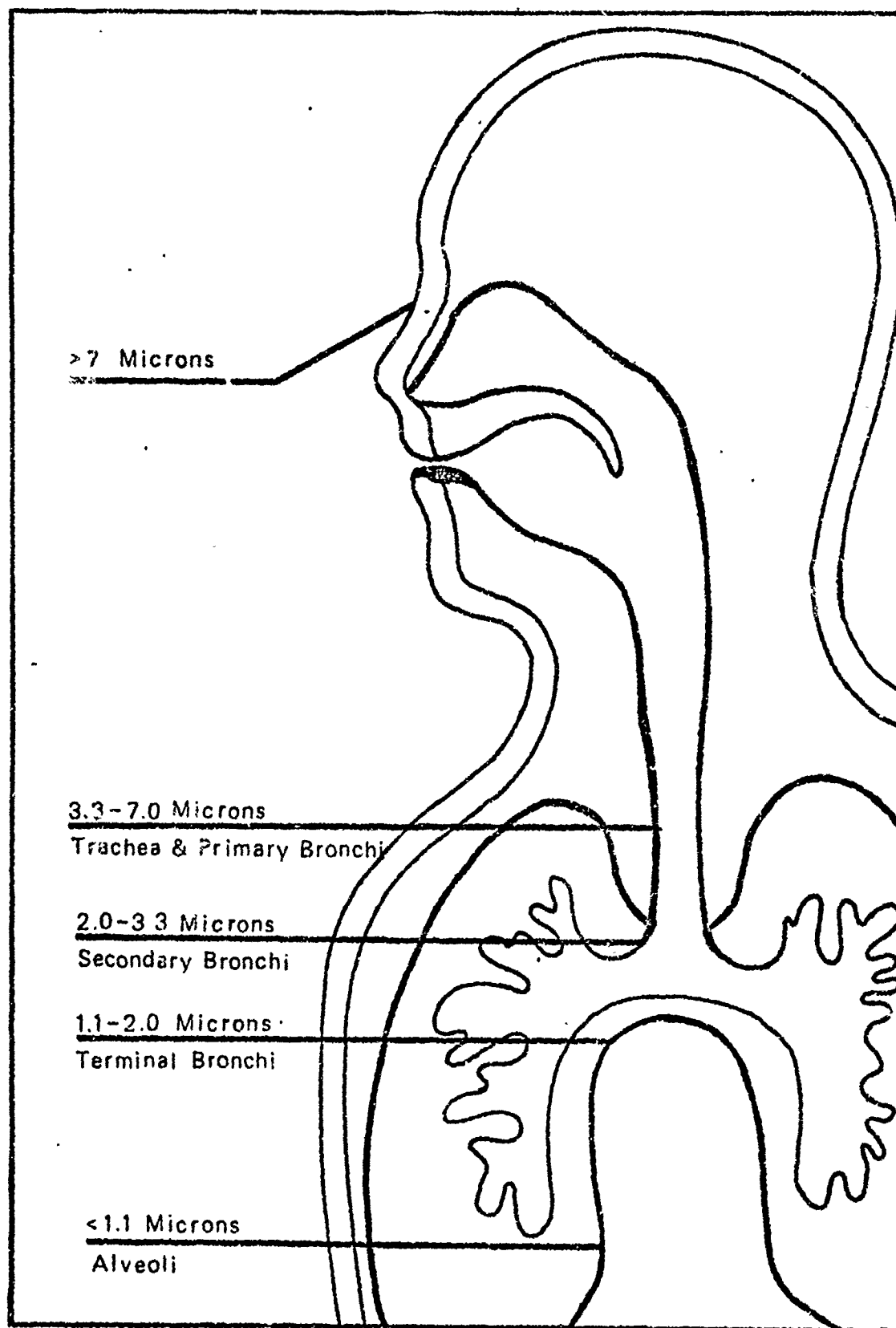


Fig. 3. Depth of Penetration of Particulates in the Human Respiratory System (Ref. 2)

per cubic meter (ng/m^3) of air on WPAFB. This level is considerably lower than the mercury content in particulates collected in Cincinnati, Ohio (Ref. 17) which showed an average content of $100 \text{ ng}/\text{m}^3$. The range of the Cincinnati samples was 30 to $210 \text{ ng}/\text{m}^3$, compared with 0.1 to $30.7 \text{ ng}/\text{m}^3$ for the samples analyzed in this study. This difference could be attributed to the large amount of coal burning industry in the Cincinnati area compared to the WPAFB area.

Data on mercury concentrations in size groups is stated in Appendix A, and summarized in Fig. 4. Correlation coefficients (Ref. 5) were calculated relating mercury concentration to particulate concentration in the five size groups considered. For stages 1 through 5 the correlation coefficients were 0.145, 0.171, 0.312, 0.431 and 0.022 respectively. For a sample size of 20 and at a 0.05 significance level none of the above coefficients establish correlation. As seen in Fig. 5, there were several high concentrations noted in the samples, but they did not appear consistently in the same size groups. Because of the inconsistency between samples, average figures cannot be used to define an accurate model of the system. It is not possible to state with certainty the reason for the erratic data obtained in the mercury analysis, but it could result from two possible factors. First, the actual mercury concentrations could appear as shown by the data, and no relationship exists between the mercury content and particle size. The other possible factor is the technique used for mercury analysis. Several times inexplicably high or low readings were noted when analyzing standard solutions and

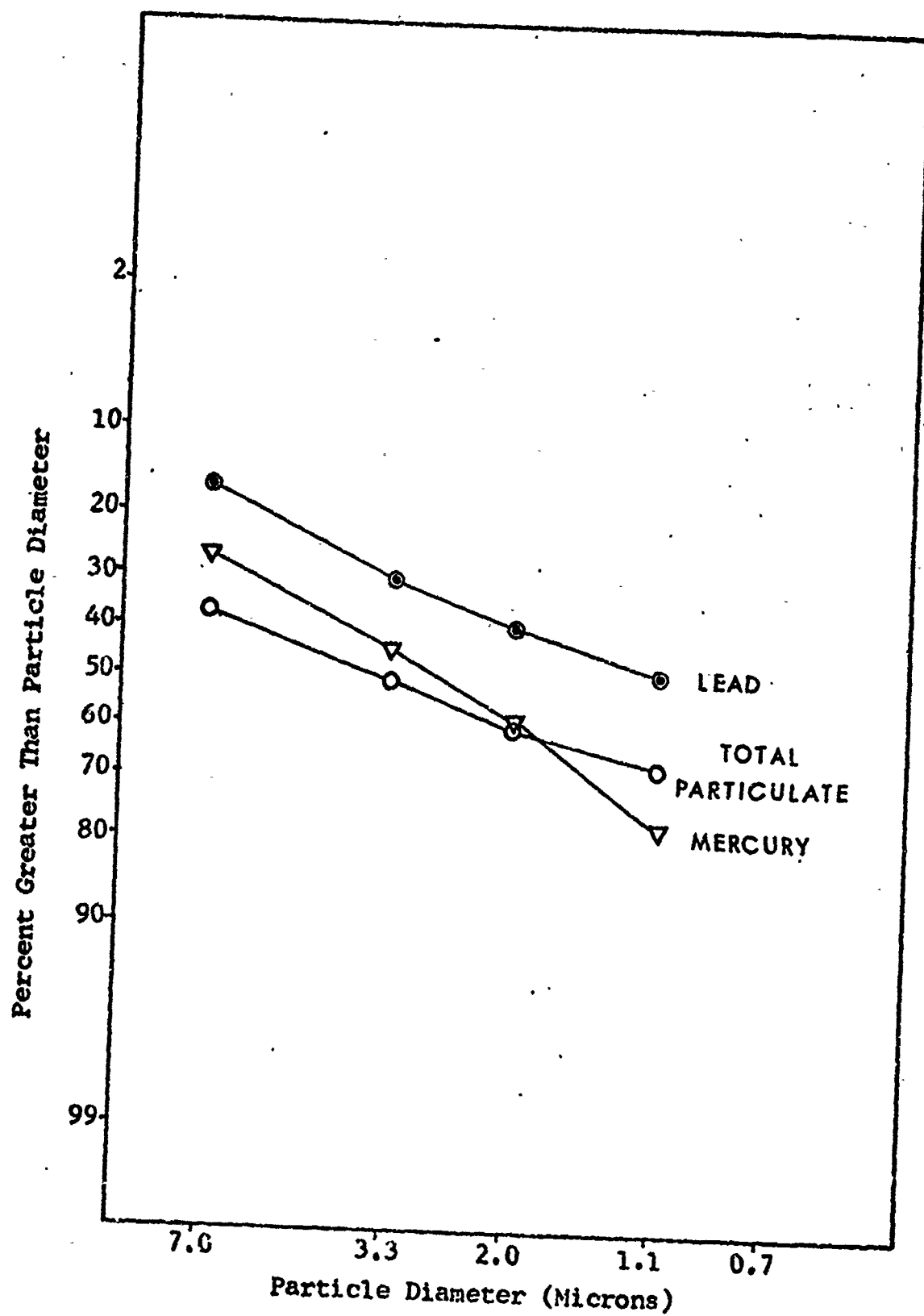


Fig. 4. Average Particle Size Distribution

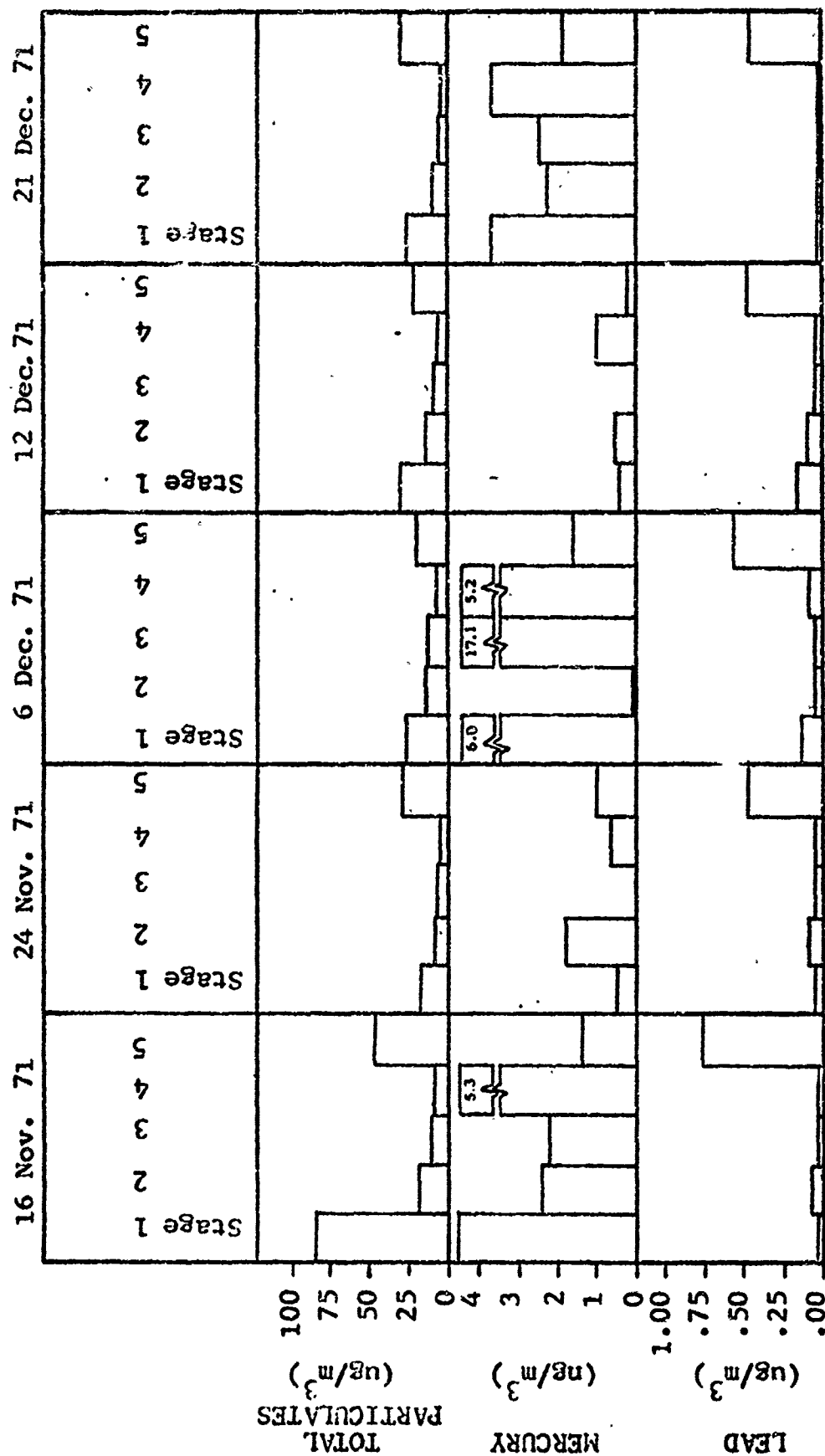


Fig. 5. Histogram of Lead, Mercury, and Particulate Concentrations

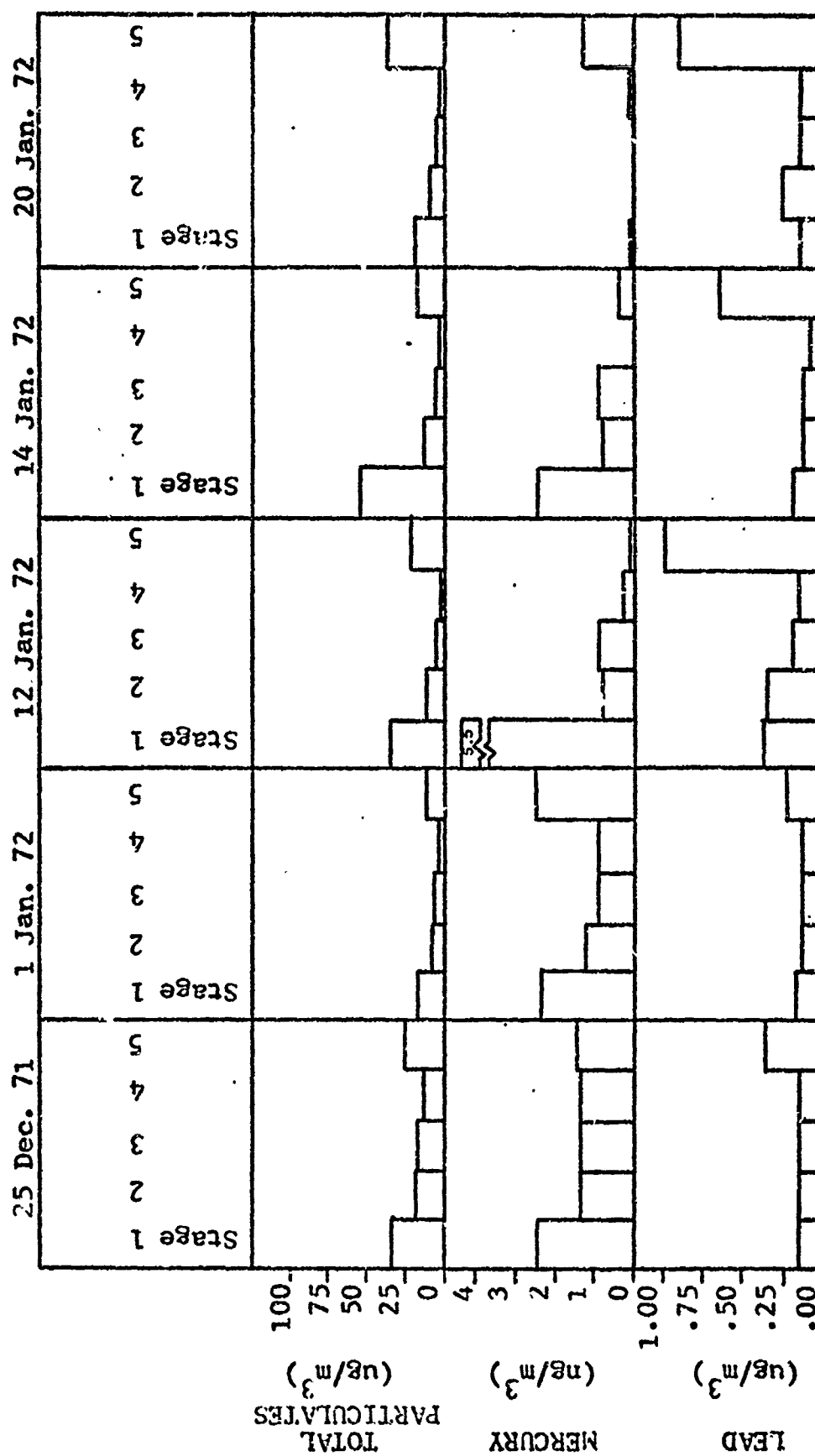


Fig. 5. Histogram of Lead, Mercury, and Particle Concentrations (Continued)

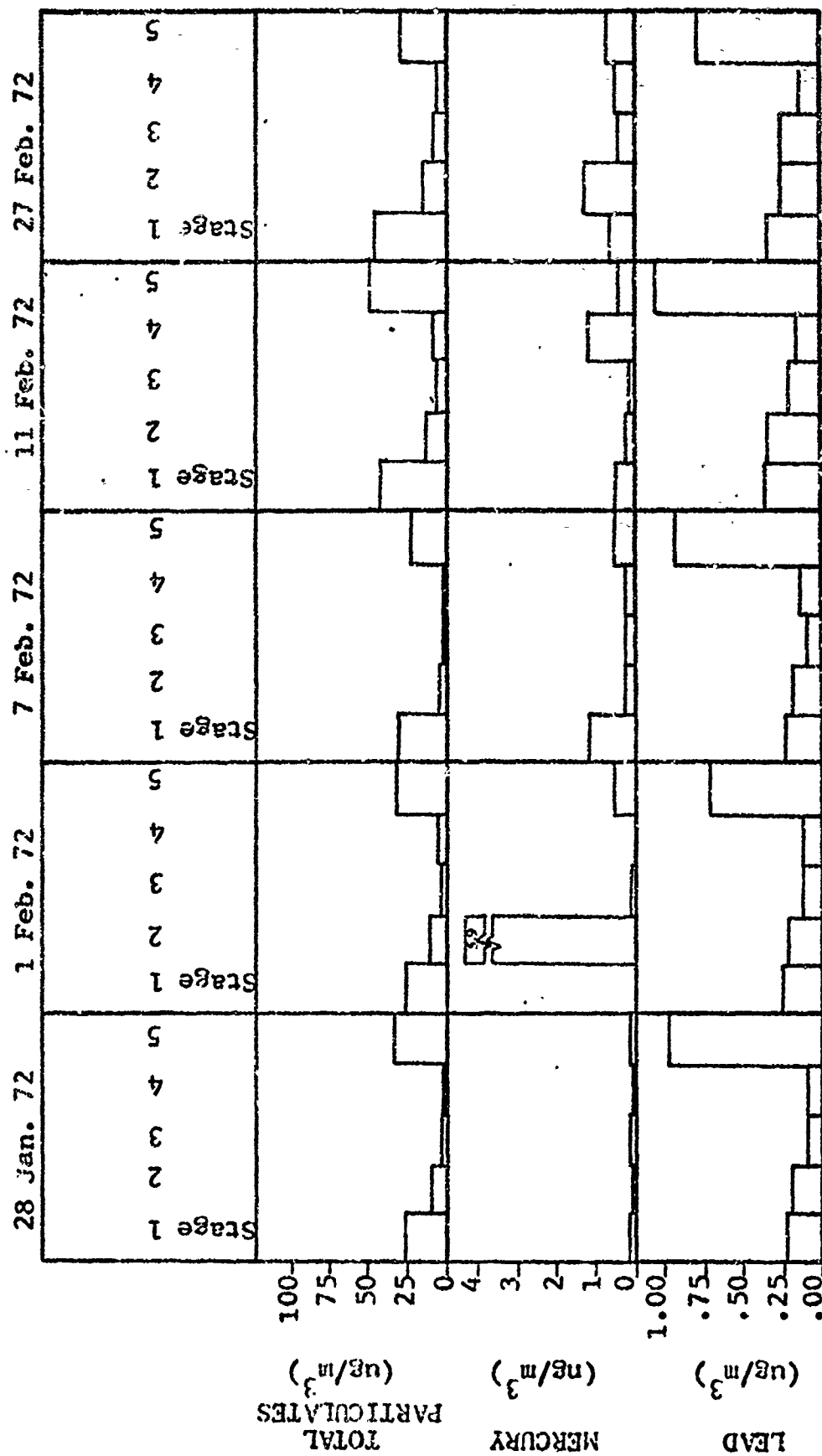


Fig. 5. Histogram of Lead, Mercury, and Particle Concentrations (Continued)

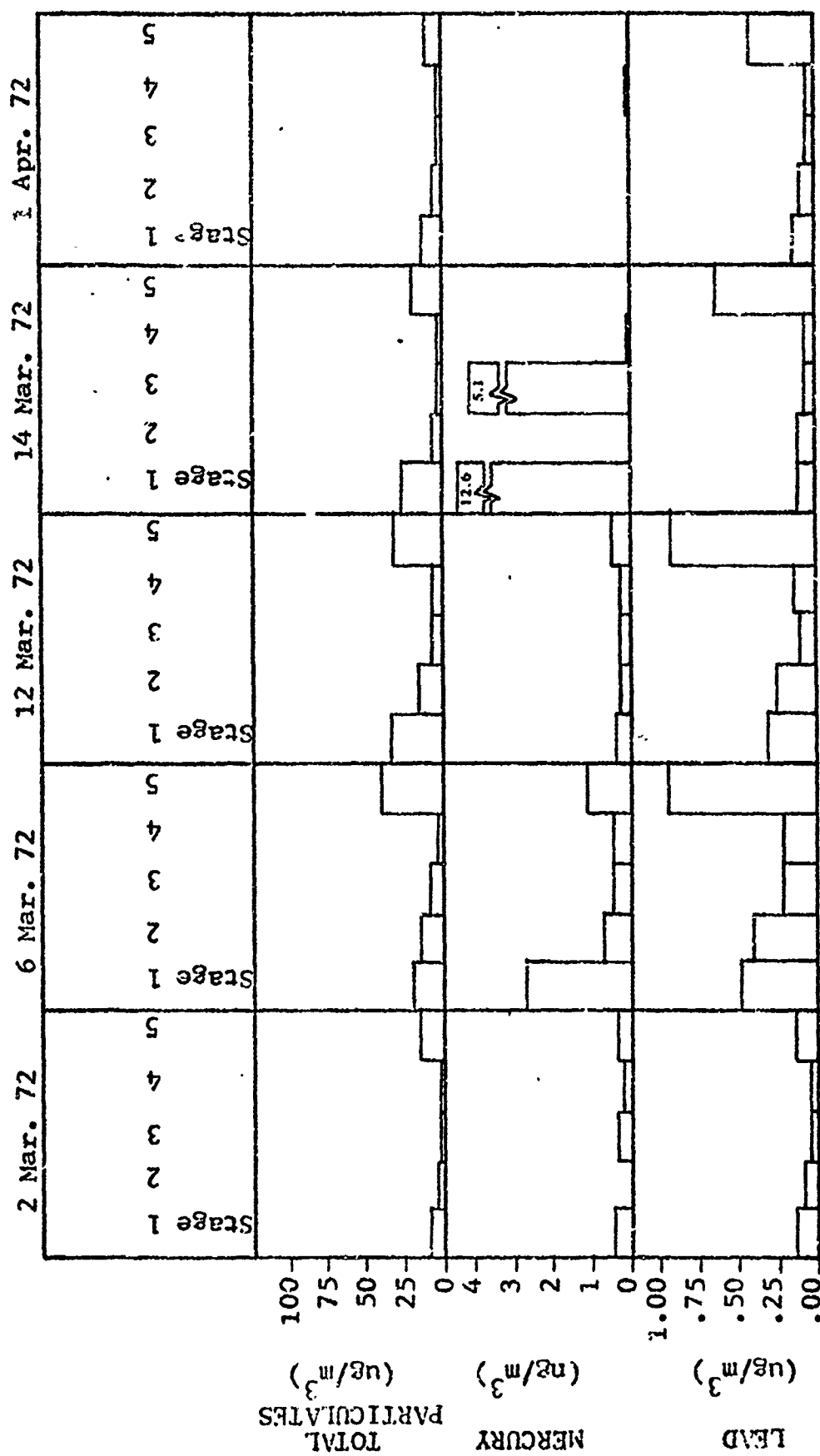


Fig. 5. Histogram of Lead, Mercury, and Particle Concentrations (Continued)

similar occurrences could explain some of the seeming inconsistent mercury concentrations. The presence of 4 or 5 erroneous results could distort any relationship which may have existed.

It is not presently known if the mercury is adsorbed on the surface of particulates, absorbed into the particles, or some combination of the adsorption and absorption. If a relationship could have been established between mercury concentration and particle size, it would be possible to postulate how the mercury is transported using the area and volume relationships for various sized particles.

It was stated in the introduction that coal was thought to be the main contributor of mercury to the local atmosphere. In an attempt to determine the amount of mercury added to the atmosphere by coal burned on WPAFB, five coal samples were analyzed for their mercury content. The results of these tests are shown in Table I. The 5-sample average value of 96.2 ppb multiplied by 500 tons of coal burned each day during the winter months implies that 0.078 pounds of mercury per day are added to the atmosphere from the base heating plants. Previous reports indicate that all mercury is released into the atmosphere when fossil fuels are burned (Ref. 15). Coal purchased by WPAFB is mined in the Snap Creek area of West Virginia.

In addition to the 20 fractionated samples analyzed, two bulk sample filters were analyzed to check the reproducibility of the mercury analysis technique. Each filter was divided into four equal sections, and the mercury concentration r

each section was determined. Assuming that the particulates are distributed evenly on the filter as was shown in Ref. 6, the concentration should be identical for each of the four sections of the same filter. The results of the 24 Feb 72 filter were quite good, varying from 0.38 to 0.72 ng/m³. In testing the samples the absorbance varied from 0.016 to 0.023. The 6 Feb 72 samples showed more variation, ranging from 0.56 to 1.52 ng/m³. The absorbance of these samples ranged from 0.020 to 0.040. Table II contains the results obtained for each filter.

At this time there is no established maximum level of mercury concentration in the atmosphere. A proposed maximum of 10,000 ng/m³ has been made by the American Conference of Governmental Industrial Hygienists (Ref. 17). However, Russian experiments have indicated that constant exposure to mercury vapor in concentrations greater than 300 ng/m³ may

Table I
Mercury Content in Coal Samples

Sample	Mercury Concentration (ppb)
1	98.9
2	95.8
3	104.7
4	55.4
5	126.1

present a health hazard (Ref. 17).

The significance of mercury content in particulates is not fully understood at this time. Several studies have been conducted to determine the concentration of mercury vapor in the atmosphere and laboratory facilities, and others to determine mercury concentration in particulates, but there has been no attempt to correlate the two aspects of mercury pollution. The EPA has selected mercury as one of the toxic elements to be monitored in the near future, and it appears that the criteria will be established in terms of mercury vapor concentration. This would require each local air pollution monitoring office to purchase mercury vapor analysis equipment. However, if a relationship exists and can be determined between mercury vapor concentration and mercury concentration in particulates, and if the offices presently have the capability to analyze particulate samples for mercury concentration, new equipment would not be required. The hi-volume particulate samples which are presently collected could be analyzed for mercury concentration and this figure converted to determine the mercury vapor concentration.

Lead Concentration

The average lead concentration of the twenty samples analyzed was 1.25×10^{-6} grams per cubic meter (ug/m^3), with concentrations ranging from 0.40 to $2.22 \text{ ug}/\text{m}^3$. These results are extremely close to those obtained in sampling near St. Louis, Missouri (Ref. 6) which ranged from 0.41 to $3.1 \text{ ug}/\text{m}^3$. They also compare quite closely with residential

area lead concentrations in Detroit and New York (Ref. 7), and Cincinnati (Ref. 13). A previous study indicated that the lead concentration composed 1.7 per cent of the total particulate concentration in Cincinnati (Ref. 13). For the samples analyzed in this study, the lead concentration was 1.5 per cent of the total particulate concentration, an exceptionally good correlation.

An average of 50.9 per cent of the lead was found to be in particles less than 1.1 microns in diameter, 9.3 per cent from 1.1 to 2.0 microns, 9.4 per cent from 2.0 to 3.3 microns, 14.2 per cent from 3.3 to 7.0 microns, and 16.2 per cent was in particles with aerodynamic diameters over 7.0 microns. Fig. 4 shows the slopes of the lines plotted for particulate concentration and lead concentration are nearly the same. Lead has a greater percentage in the size group under 1.1 microns, but the groups from 1.1 microns to 7.0 microns show a remarkable similarity between percentage of total particulates and percentage of total lead contained in the size range. The factor of primary importance, however, is the high concentration of lead in particulates less than 1.1 micron.

Two bulk sample filters were divided into four equal areas each and analyzed to check the reproducibility of the lead analysis method. Assuming uniform distribution of particulates (Ref. 6), equal lead concentrations were expected for each section of the same filter. Results of the tests were excellent and are shown in Table III.

The EPA has not established maximum limits for lead concentrations in ambient air. Tests conducted at a mountain

Table II
Reproducibility of
Mercury Analysis

Sample	Mercury Concentration ($\mu\text{g}/\text{m}^3$)
6 Feb 72	
1	1.52
2	0.56
3	1.19
4	1.38
24 Feb 72	
1	0.38
2	0.42
3	0.38
4	0.72

Table III
Reproducibility of
Lead Analysis

Sample	Lead Conc. ($\mu\text{g}/\text{m}^3$)
11 Jan 72	
1	3.46
2	3.11
3	3.34
4	3.46
29 Jan 72	
1	2.21
2	2.27
3	2.30
4	2.27

site in southern California with no vehicular traffic or industrial activity near it yielded an average lead concentration of 0.05 ug/m^3 (Ref. 11), far below the concentrations experienced by residents of our nation's large cities, or even semi-rural areas such as WPAFB.

Opinions on the importance of lead concentrations in the atmosphere are varied. A recent report by an adhoc panel of the National Research Council's Committee on Biologic Effects of Atmospheric Pollutants reports that "for an average city resident, the total exposure produces a blood lead concentration about half that necessary to cause biochemical changes in the body and one-fourth the level at which symptoms of lead poisoning begin to occur" (Ref. 12). Another report, however, states that the idea of biochemical changes occurring above a line and not occurring at concentrations below that line is simply not true. Rather, for any concentration above the natural level for man, the body is effected to varying degrees (Ref. 16). Much work needs to be done in the area of defining the effects of lead on man. We know that approximately 40 per cent of the lead ingested into the lungs is absorbed by the body. Only about 5 per cent of the lead consumed in food is absorbed into the body (Ref. 16), thus indicating the importance of controlling the lead concentrations in the atmosphere.

Results of Stochastic Analysis

The variable of primary interest in the modeling study was the total particulate concentration. Ninety samples were

taken between 10 Nov 71 and 3 Apr 72, 56 using the Anderson sampler head and 34 bulk samples. The results of the data analysis are shown in the upper portion of Table IV. The limits of the Reverse Arrangements test are shown at the 0.1 level of significance, and the total number of reverse arrangements shown immediately below. The number of reverse arrangements was well within the established limits, thus confirming the previous assumption of randomness. The remaining columns show the results of the K-S test, the Likelihood Ratio (LR) test, the corresponding parameters of the functions isolated by the K-S and LR test, and the first and second moments of the functions. The K-S test accepted five density functions; Largest Extreme Value, Lognormal, Gamma, Weibull, and Beta*. Of these, the LR test isolated the Lognormal as the function best describing the data. The number of functions passing the K-S test was not unusual considering the relatively small sample size. Since the maximum allowable K-S statistic, $d_{\alpha}(N)$, was 0.1128 and the maximum difference for the Lognormal density function was 0.0570, the null hypothesis of Lognormality was accepted.

Also of interest was the distribution of particulates in the 5 size groups; greater than 7.0, 3.3 to 7.0, 2.0 to 3.3, 1.1 to 2.0, and less than 1.1 microns. The particulate concentrations in each of these size groups was analyzed using the computer program described above, and the results are shown in the lower portion of Table IV. The concentrations of particulates greater than 7.0 microns were also best described by the Lognormal density function. The concentra-

tions of the 3.3 to 7.0 micron particles were best described by the Gamma density function, the parameters of which are also shown in Table IV. The Reverse Arrangements test rejected randomness at the 0.10 level of significance, but accepted at the 0.05 level for this size group. For the sample size $N = 56$ the randomness of the particulate concentrations in the 2.0 to 3.3 and 1.1 to 2.0 micron size groups could not be established by the Reverse Arrangements test at any level of significance, hence could not be analyzed stochastically. The importance of this finding is not fully understood at this time. If future studies of this nature are made, it is recommended that consideration be given to why data from these two size groups are not accepted as random when data from other size groups are. The most critical of the particle size groups analyzed is that less than 1.1 microns. These particles are almost permanently suspended in the atmosphere unless washed out by precipitation, and also have the deepest penetration in the respiratory system. Randomness was established at the 0.10 level of significance, and the K-S test passed 5 density functions, Largest Extreme Value, Lognormal, Gamma, Weibull, and Beta. The LR test isolated the Beta function to best describe the data, and the parameters are given in Table IV.

Using the information given in Table IV and the definitions of the density functions in Appendix D, the probability of particulate concentrations exceeding certain levels can be determined for WPAFB, Ohio. An example using the Lognormal density function to calculate the probability of total

particulate concentrations exceeding 120 ug/m^3 is included in
Appendix E.

Table IV
Results of Stochastic Analysis

Variable	Sample Size	R. A. Limits A_i	K-S Test	Likelihood Ratio Test	Parameters					
					Lognormal Parameters			Gamma Parameters		
					Mean	Variance	Mode	Mean	Var.	Median
Total Particulates	90	1767 - 2238 2235	Largest Ext. Val. Lognormal Gamma Weibull Beta*	Lognormal	85.13	1048.17	69.52			79.57
>7	56	654 - 886 785	Largest Ext. Val. Lognormal Weibull Beta*	Lognormal	32.15	226.97	23.87			29.11
3.3 - 7.0	56	631 - 909 ⁽¹⁾ 902	Lognormal Gamma Weibull	Gamma	Shape 1.40	Scale 5.10	Location 6.09	Mean 13.23		Var. 36.41
2.0 - 3.3	56	654 - 886 1021	Randomness Not Established							
1.1 - 2.0	56	654 - 886 993	Randomness Not Established							
<1.1	56	654 - 886 816	Largest Ex. Val. Lognormal Gamma Weibull Beta	Beta	Shape (A) 1.13	Shape (B) 8.50	Scale 11.73	Loc. 13.03	Mean 26.17	Var. 121.89

(From Ref. 20:413)

(1) R. A. Limits at 0.05 level of significance

V. Conclusions

Mercury and lead concentrations and distributions in particulates as well as the total concentration of suspended particulates on WPAFB have been considered in this study. Several conclusions have been reached and are listed below:

1. A significant portion of the total particulates (31.1 per cent) were below 1.1 microns in diameter.
2. The average lead concentration on WPAFB was 1.25 ug/m^3 ; this statistic agrees well with studies conducted in other midwestern cities. Although no linear correlation was found between lead concentration and particulate concentration in the various size groups, over half (50.9 per cent) of the lead was in particulates less than 1.1 microns in diameter.
3. Mercury concentrations were quite low when compared to recommended standards for the United States. No linear correlation between mercury concentration and particle size was found.
4. West Virginia coal burned on WPAFB was found to contain 96.2 ppb mercury. The total amount of mercury added to the atmosphere by burning coal on WPAFB was estimated at 0.078 pounds per day during the winter months. This figure is well within federal emissions standards of 5 pounds

per day for each plant (Ref. 9).

5. The Lognormal density function was found to best describe the data collected on total particulate concentrations. By using the parameters of the Lognormal function the probability of future particulate concentrations on WPAFB may be stated.
6. The Beta density function was isolated as the function best describing the particulates less than 1.1 micron in aerodynamic diameter.

VI. Recommendations

The following recommendations are made as a result of the findings of this study:

1. A closed system should be used in future mercury analysis of particulates. Such a system could be easily achieved by connecting a small pump to move the air contained in the system, and recycling the air until a constant absorbance is obtained for the sample. The system would be purged after each mercury analysis. The proposed system would eliminate many possible sources of error which exist in the present system.

2. A study should be conducted to determine the relationship between atmospheric mercury vapor concentrations and particulate mercury concentrations. This study should be undertaken as soon as possible so the EPA can use the information in their program for monitoring mercury concentrations in the atmosphere.

3. A study similar to the one reported here should be conducted on WPAFB after the heating plants have been converted from coal to oil or natural gas. This follow-on study would determine what effect the change in fuels has had on the quality of ambient air on the base.

4. A continuing program to periodically analyze particulate samples for lead concentration should be established. As more automobiles burn lead-free or low-lead-content gasoline, the lead content in ambient air should decrease. A

program to monitor lead concentrations in the atmosphere is necessary to verify the predicted decreases.

5. The findings in this report should be used in further studies of the ecosystem of WPAFB. The atmosphere is only one part of man's environment, and other aspects of that environment must also be studied in order to better understand the possible dangers that man may encounter in the future. As the total ecosystem is understood, the resources available to man can be used to the greatest advantage.

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Appendix A

Data From 24-Hour Hi-Volume

Ambient Air Samples

Data displayed in Table V were collected from three sampling sites on WPAFB. Data from 10 November 71 through 2 December 71 were collected from Site I, 4 December 71 through 7 January 72 were from Site II, and 9 January 72 through 3 April 72 were collected from Site III.

Table V
DATA FROM 24-HOUR HI-VOLUME AMBIENT AIR SAMPLES

Sample	Particulate Weight (gm)	Volume Sampled (m ³)	Particulate Conc. (ug/m ³)	Mercury Conc. (ug/m ³)	Lead Conc. (ug/m ³)
10 Nov 71 Bulk	0.0917	868.5	105.6	---(1)	---
12 Nov 71					
1	0.0899	812.7	110.6	---	---
2	0.0330	812.7	40.7	---	---
3	0.0206	812.7	25.3	---	---
4	0.0172	812.7	21.2	---	---
5	0.0426	812.7	52.4	---	---
Total	0.2033	812.7	250.1		
14 Nov 71					
1	.0304	787.2	38.6	---	---
2	.0169	787.2	21.5	---	---
3	.0091	787.2	11.6	---	---
4	.0078	787.2	9.9	---	---
5	.0211	787.2	26.8	---	---
Total	.0853	787.2	108.3		
16 Nov 71					
1	.0693	824.0	84.1	.0044	0.07
2	.0175	824.0	21.2	.0024	0.11
3	.0099	824.0	12.0	.0022	0.07
4	.0090	824.0	10.9	.0053	0.07
5	.0376	824.0	45.6	.0014	0.76
Total	.1433	824.0	173.9	0.0157	1.08
18 Nov 71					
1	.0271	813.8	33.2	---	---
2	.0136	813.8	16.7	---	---
3	.0073	813.8	9.0	---	---
4	.0063	813.8	7.7	---	---
5	.0236	813.8	29.0	---	---
Total	.0779	813.8	95.7		

(1) Sample not analyzed.

Table V
(Continued)

DATA FROM 2-HOUR HI-VOLUME AMBIENT AIR SAMPLES

Sample	Particulate Weight (g)	Volume Sampled (m ³)	Particulate Conc. (ug/m ³)	Mercury Conc. (ug/m ³)	Lead Conc. (ug/m ³)
20 Nov 71					
1	.0152	815.5	18.6	---	---
2	.0083	815.5	10.2	---	---
3	.0048	815.5	5.9	---	---
4	.0023	815.5	2.8	---	---
5	.0369	815.5	45.2	---	---
Total	.0675	815.5	82.8		
22 Nov 71					
1	.0165	812.7	20.3	---	---
2	.0057	812.7	7.0	---	---
3	.0036	812.7	4.4	---	---
4	.0021	812.7	2.6	---	---
5	.0114	812.7	14.0	---	---
Total	.0393	812.7	48.3		
24 Nov 71					
1	.0151	812.7	18.6	.0005	0.06
2	.0094	812.7	11.6	.0018	0.10
3	.0086	812.7	10.6	.0007	0.06
4	.0079	812.7	9.7	.0000	0.06
5	.0230	812.7	28.3	.0010	0.44
Total	.0640	812.7	78.8	.0040	0.72
28 Nov 71					
1	.0199	815.5	24.4	---	---
2	.0086	815.5	10.5	---	---
3	.0073	815.5	8.9	---	---
4	.0071	815.5	8.7	---	---
5	.0163	815.5	20.0	---	---
Total	.0592	815.5	72.6		
30 Nov 71					
1	.0129	811.0	15.9	---	---
2	.0050	811.0	6.2	---	---
3	.0044	811.0	5.4	---	---
4	.0038	811.0	4.7	---	---
5	.0107	811.0	13.2	---	---
Total	.0368	811.0	45.4		

Table V
(Continued)

DATA FROM 24-HOUR HI-VOLUME AMBIENT AIR SAMPLES

Sample	Particulate Weight (g)	Volume Sampled (m ³)	Particulate Conc. (ug/m ³)	Mercury Conc. (ug/m ³)	Lead Conc. (ug/m ³)
2 Dec 71					
1	.0308	801.4	38.4	---	---
2	.0109	801.4	13.6	---	---
3	.0074	801.4	9.2	---	---
4	.0054	801.4	6.7	---	---
5	.0187	801.4	23.3	---	---
Total	.0732	801.4	91.3		
6 Dec 71					
1	.0216	812.7	26.6	.0060	0.14
2	.0108	812.7	13.0	.0001	0.06
3	.0104	812.7	12.8	.0177	0.06
4	.0073	812.7	9.0	.0052	0.10
5	.0165	812.7	20.3	.0017	0.59
Total	.0664	812.7	81.7	.0307	0.95
8 Dec 71					
1	.0338	807.0	41.9	---	---
2	.0131	807.0	16.2	---	---
3	.0106	807.0	13.1	---	---
4	.0092	807.0	11.4	---	---
5	.0409	807.0	50.7	---	---
Total	.1076	807.0	133.3		
10 Dec 71					
1	.0424	815.5	52.0	---	---
2	.0248	815.5	30.4	---	---
3	.0182	815.5	22.3	---	---
4	.0138	815.5	16.9	---	---
5	.0178	815.5	21.8		
Total	.1170	815.5	143.4		
12 Dec 71					
1	.0238	812.7	29.3	.0004	0.15
2	.0123	812.7	15.1	.0005	0.07
3	.0094	812.7	11.6	.0000	0.04
4	.0081	812.7	9.9	.0010	0.04
5	.0191	812.7	23.5	.0002	0.48
Total	.0727	812.7	89.5	.0021	0.78

Table 5
(Continued)

DATA FROM 24-HOUR HI-VOLUME AMBIENT AIR SAMPLES

Sample	Particulate Weight (gm)	Volume Sampled (m ³)	Particulate Conc. (ug/m ³)	Mercury Conc. (ug/m ³)	Lead Conc. (ug/m ³)
14 Dec 71					
1	.0124	812.7	15.2	---	---
2	.0088	812.7	10.8	---	---
3	.0068	812.7	8.4	---	---
4	.0060	812.7	7.4	---	---
5	<u>.0513</u>	<u>812.7</u>	<u>63.1</u>	---	---
Total	.0853	212.7	104.9		
16 Dec 71					
1	.0172	843.9	20.4	---	---
2	.0075	843.9	8.9	---	---
3	.0052	843.9	6.2	---	---
4	.0046	843.9	5.5	---	---
5	<u>.0216</u>	<u>843.9</u>	<u>25.6</u>	---	---
Total	.0561	843.9	66.5		
18 Dec 71					
1	.0371	807.0	45.9	---	---
2	.0187	807.0	23.2	---	---
3	.0140	807.0	17.3	---	---
4	.0110	807.0	13.6	---	---
5	<u>.0172</u>	<u>807.0</u>	<u>21.3</u>	---	---
Total	.0980	807.0	121.4		
21 Dec 71					
1	.0208	818.4	25.4	.0037	0.07
2	.0083	818.4	10.1	.0022	0.07
3	.0060	818.4	7.3	.0024	0.04
4	.0062	818.4	7.6	.0037	0.07
5	<u>.0237</u>	<u>818.4</u>	<u>28.9</u>	<u>.0019</u>	<u>0.47</u>
Total	.0650	818.4	79.4	.0139	0.72
23 Dec 71					
1	.0573	838.2	68.4	---	---
2	.0248	838.2	29.6	---	---
3	.0159	838.2	19.0	---	---
4	.0174	838.2	20.7	---	---
5	<u>.0213</u>	<u>838.2</u>	<u>25.4</u>	---	---
Total	.1367	838.2	163.1		

Table 5
(Continued)

DATA FROM 24-HOUR HI-VOLUME AMBIENT AIR SAMPLES

Sample	Particulate Weight (gm)	Volume Sampled (m ³)	Particulate Conc. (ug/m ³)	Mercury Conc. (ug/m ³)	Lead Conc. (ug/m ³)
25 Dec 71					
1	.0254	809.9	31.4	.0024	0.12
2	.0149	809.9	18.4	.0013	0.12
3	.0142	809.9	17.5	.0013	0.12
4	.0123	809.9	15.2	.0013	0.12
5	<u>.0206</u>	<u>809.9</u>	<u>25.4</u>	<u>.0014</u>	<u>0.34</u>
Total	.0874	809.9	107.9	.0077	0.82
30 Dec 71					
1	.0107	852.4	12.6	---	---
2	.0110	852.4	12.9	---	---
3	.0029	852.4	3.4	---	---
4	.0022	852.4	2.6	---	---
5	<u>.0068</u>	<u>852.4</u>	<u>7.9</u>	<u>---</u>	<u>---</u>
Total	.0336	852.4	39.4		
1 Jan 72					
1	.0131	818.4	16.0	.0023	0.16
2	.0063	818.4	7.7	.0012	0.12
3	.0059	818.4	7.2	.0009	0.12
4	.0042	818.4	5.1	.0009	0.12
5	<u>.0102</u>	<u>818.4</u>	<u>12.5</u>	<u>.0025</u>	<u>0.23</u>
Total	.0397	818.4	48.5	.0078	0.75
6 Jan 72					
Bulk	.2148	1574.4	136.4	---	---
7 Jan 72					
Bulk	.0975	1854.8	52.6	---	---
9 Jan 72					
Bulk	.0951	1642.4	57.9	---	---
10 Jan 72					
1	.0295	816.7	36.1	---	---
2	.0089	816.7	10.9	---	---
3	.0046	816.7	5.6	---	---
4	.0040	816.7	4.9	---	---
5	<u>.0200</u>	<u>816.7</u>	<u>24.5</u>	<u>---</u>	<u>---</u>
Total	.0670	816.7	82.0		

Table 5
(Continued)

DATA FROM 24-HOUR HI-VOLUME AMBIENT AIR SAMPLES

Sample	Particulate Weight (μg)	Volume Sampled (m^3)	Particulate Conc. ($\mu\text{g}/\text{m}^3$)	Mercury Conc. (ng/m^3)	Lead Conc. (ng/m^3)
11 Jan 72 Bulk	0.0904	811.6	111.4	---	---
12 Jan 72					
1	.0274	792.0	34.6	.0055	0.33
2	.0094	792.0	11.9	.0008	0.30
3	.0041	792.0	5.2	.0009	0.18
4	.0014	792.0	1.8	.0003	0.14
5	<u>.0181</u>	<u>792.0</u>	<u>22.8</u>	<u>.0001</u>	<u>0.99</u>
Total	.0604	792.0	76.3	.0076	1.94
13 Jan 72 Bulk	.0274	790.0	34.7	---	---
14 Jan 72					
1	.0470	859.1	54.7	.0024	0.20
2	.0120	859.1	14.0	.0008	0.14
3	.0054	859.1	6.3	.0009	0.14
4	.0038	859.1	4.4	.0000	0.10
5	<u>.0161</u>	<u>859.1</u>	<u>18.7</u>	<u>.0004</u>	<u>0.63</u>
Total	.0843	859.1	98.1	.0045	1.21
15 Jan 72 Bulk	.0621	1012.3	61.3	---	---
16 Jan 72					
1	.0235	863.5	27.2	---	---
2	.0093	863.5	10.8	---	---
3	.0039	863.5	4.5	---	---
4	.0022	863.5	2.5	---	---
5	<u>.0149</u>	<u>863.5</u>	<u>17.2</u>	---	---
Total	.0538	863.5	62.3		
17 Jan 72 Bulk	.0822	978.6	84.0	---	---

Table 5
(Continued)

DATA FROM 24-HOUR HI-VOLUME AMBIENT AIR SAMPLES

Sample	Particulate Weight (gm)	Volume Sampled (m ³)	Particulate Conc. (ug/m ³)	Mercury Conc. (ug/m ³)	Lead Conc. (ug/m ³)
18 Jan 72					
1	.0183	809.9	22.6	---	---
2	.0078	809.9	9.6	---	---
3	.0052	809.9	6.4	---	---
4	.0029	809.9	3.6	---	---
5	<u>.0177</u>	<u>809.9</u>	<u>21.8</u>	---	---
Total	.0519	809.9	64.1		
19 Jan 72					
Bulk	.0951	1019.4	93.3	---	---
20 Jan 72					
1	.0151	781.6	19.3	.0001	0.14
2	.0075	781.6	9.6	.0000	0.26
3	.0044	781.6	5.6	.0000	0.14
4	.0038	781.6	4.9	.0002	0.14
5	<u>.0278</u>	<u>781.6</u>	<u>35.6</u>	<u>.0013</u>	<u>0.89</u>
Total	.0586	781.6	75.0	.0016	1.57
21 Jan 72					
Bulk	.0704	1108.1	63.5	---	---
22 Jan 72					
1	.0138	807.0	17.1	---	---
2	.0052	807.0	6.4	---	---
3	.0042	807.0	5.2	---	---
4	.0047	807.0	5.8	---	---
5	<u>.0135</u>	<u>807.0</u>	<u>16.7</u>	---	---
Total	.0414	807.0	51.3		
23 Jan 72					
Bulk	.0424	1008.8	42.0	---	---
24 Jan 72					
1	.0149	815.5	18.3	---	---
2	.0089	815.5	9.8	---	---
3	.0052	815.5	6.4	---	---
4	.0030	815.5	3.7	---	---
5	<u>.0121</u>	<u>815.5</u>	<u>14.8</u>	---	---
Total	.0432	815.5	52.9		

Table 5
(Continued)

DATA FROM 24-HOUR HI-VOLUME AMBIENT AIR SAMPLES

Sample	Particulate Weight (μm)	Volume Sampled (m^3)	Particulate Conc. ($\mu\text{g}/\text{m}^3$)	Mercury Conc. ($\mu\text{g}/\text{m}^3$)	Lead Conc. ($\mu\text{g}/\text{m}^3$)
25 Jan 72 Bulk	.0616	1018.0	60.5	---	---
26 Jan 72					
1	.0163	811.0	20.1	---	---
2	.0064	811.0	7.9	---	---
3	.0025	811.0	3.1	---	---
4	.0022	811.0	2.7	---	---
5	.0149	811.0	18.4	---	---
Total	.0423	811.0	52.2		
27 Jan 72 Bulk	.0536	954.9	56.1	---	---
28 Jan 72					
1	.0290	910.4	31.8	.0002	0.23
2	.0085	910.4	9.3	.0001	0.19
3	.0035	910.4	3.8	.0002	0.11
4	.0024	910.4	2.6	.0001	0.11
5	.0233	910.4	25.6	.0002	0.94
Total	.0667	910.4	73.3	.0008	1.58
29 Jan 72 Bulk	.1484	987.2	150.3	---	---
30 Jan 72					
1	.0286	812.7	35.2	---	---
2	.0094	812.7	11.6	---	---
3	.0043	812.7	5.3	---	---
4	.0036	812.7	4.4	---	---
5	.0206	812.7	25.3	---	---
Total	.0665	812.7	81.8		
31 Jan 72 Bulk	.1142	1021.9	111.7	---	---

Table 5
(Continued)

DATA FROM 24-HOUR HI-VOLUME AMBIENT AIR SAMPLES

Sample	Particulate Weight (μm)	Volume Sampled (m^3)	Particulate Conc. ($\mu\text{g}/\text{m}^3$)	Mercury Conc. ($\mu\text{g}/\text{m}^3$)	Lead Conc. ($\mu\text{g}/\text{m}^3$)
1 Feb 72					
1	.0201	792.9	25.3	.0000	0.26
2	.0077	792.9	9.7	.0059	0.22
3	.0037	792.9	4.7	.0001	0.13
4	.0043	792.9	5.4	.0000	0.13
5	<u>.0235</u>	<u>792.9</u>	<u>29.6</u>	<u>.0005</u>	<u>0.72</u>
Total	.0593	792.9	74.8	.0065	1.46
2 Feb 72					
Bulk	.1082	995.5	108.7	---	---
3 Feb 72					
1	.0324	812.7	39.9	---	---
2	.0208	812.7	25.6	---	---
3	.0106	812.7	13.0	---	---
4	.0058	812.7	7.1	---	---
5	<u>.0221</u>	<u>812.7</u>	<u>27.2</u>	---	---
Total	.0917	812.7	112.8		
4 Feb 72					
Bulk	.0921	1040.7	88.5	---	---
5 Feb 72					
1	.0263	801.8	32.8	---	---
2	.0101	801.8	12.6	---	---
3	.0059	801.8	7.4	---	---
4	.0040	801.8	4.9	---	---
5	<u>.0179</u>	<u>801.8</u>	<u>22.3</u>	---	---
Total	.0642	801.8	80.1		
6 Feb 72					
Bulk	.0481	1012.3	47.5	---	---
7 Feb 72					
1	.0243	808.2	30.1	.0012	0.24
2	.0052	808.2	6.4	.0003	0.20
3	.0030	808.2	3.7	.0003	0.12
4	.0019	808.2	2.3	.0003	0.16
5	<u>.0096</u>	<u>808.2</u>	<u>24.2</u>	<u>.0006</u>	<u>0.90</u>
Total	.0540	808.2	66.8	.0027	1.62

Table 5
(Continued)

DATA FROM 24-HOUR HI-VOLUME AMBIENT AIR SAMPLES

Sample	Particulate Weight (gm)	Volume Sampled (m ³)	Particulate Conc. (ug/m ³)	Mercury Conc. (ug/m ³)	Lead Conc. (ug/m ³)
8 Feb 72 Bulk	.1470	1001.8	146.7	---	---
9 Feb 72					
1	.0196	809.9	24.2	---	---
2	.0112	809.9	13.8	---	---
3	.0060	809.9	7.4	---	---
4	.0064	809.9	7.9	---	---
5	<u>.0365</u>	<u>809.9</u>	<u>45.1</u>	---	---
Total	.0797	809.9	98.4		
10 Feb 72 Bulk	.1198	999.0	119.9	---	---
11 Feb 72					
1	.0345	825.2	41.8	.0006	0.35
2	.0116	825.2	14.1	.0003	0.31
3	.0077	825.2	9.3	.0002	0.23
4	.0087	825.2	10.5	.0012	0.20
5	<u>.0412</u>	<u>825.2</u>	<u>49.9</u>	<u>.0005</u>	<u>1.11</u>
Total	.1037	825.2	125.7	.0028	2.20
12 Feb 72 Bulk	.1254	1175.9	106.6	---	---
15 Feb 72					
1	.0216	795.7	27.1	---	---
2	.0069	795.7	8.7	---	---
3	.0042	795.7	5.3	---	---
4	.0034	795.7	4.3	---	---
5	<u>.0149</u>	<u>795.7</u>	<u>18.7</u>	---	---
Total	.0510	795.7	64.1		
16 Feb 72 Bulk	.0974	999.0	97.5	---	---

Table 5
(Continued)

DATA FROM 24-HOUR HI-VOLUME AMBIENT AIR SAMPLES

Sample	Particulate Weight (gm)	Volume Sampled (m ³)	Particulate Conc. (ug/m ³)	Mercury Conc. (ug/m ³)	Lead Conc. (ug/m ³)
17 Feb 72					
1	.0272	812.7	33.5	---	---
2	.0092	812.7	11.3	---	---
3	.0055	812.7	6.8	---	---
4	.0034	812.7	4.2	---	---
5	<u>.0207</u>	<u>812.7</u>	<u>25.5</u>	---	---
Total	.0660	812.7	81.2		
18 Feb 72					
Bulk	.0999	1026.5	97.3	---	---
19 Feb 72					
1	.0184	796.6	23.1	---	---
2	.0065	796.6	8.2	---	---
3	.0029	796.6	3.6	---	---
4	.0013	796.6	1.6	---	---
5	<u>.0081</u>	<u>796.6</u>	<u>10.2</u>	---	---
Total	.0372	796.6	46.7		
20 Feb 72					
Bulk	.0739	1015.9	72.7	---	---
21 Feb 72					
1	.0245	801.4	30.6	---	---
2	.0110	801.4	13.7	---	---
3	.0055	801.4	6.9	---	---
4	.0041	801.4	5.1	---	---
5	<u>.0182</u>	<u>801.4</u>	<u>22.7</u>	---	---
Total	.0633	801.4	78.9		
22 Feb 72					
Bulk	.0525	985.2	51.8	---	---
23 Feb 72					
1	.0230	824.0	27.9	---	---
2	.0087	824.0	10.6	---	---
3	.0043	824.0	5.2	---	---
4	.0050	824.0	6.1	---	---
5	<u>.0225</u>	<u>824.0</u>	<u>27.3</u>	---	---
Total	.0635	824.0	77.1		

Table 5
(Continued)

DATA FROM 24-HOUR HI-VOLUME AMBIENT AIR SAMPLES

Sample	Particulate Weight (μg)	Volume Sampled (m^3)	Particulate Conc. ($\mu\text{g}/\text{m}^3$)	Mercury Conc. (ng/m^3)	Lead Conc. ($\mu\text{g}/\text{m}^3$)
24 Feb 72 Bulk	.0831	995.6	83.5	---	---
25 Feb 72					
1	.0262	826.9	31.7	---	---
2	.0114	826.9	13.8	---	---
3	.0068	826.9	8.2	---	---
4	.0076	826.9	9.2	---	---
5	<u>.0279</u>	<u>826.9</u>	<u>33.7</u>	---	---
Total	.0799	826.9	96.6		
26 Feb 72 Bulk	.0847	1005.3	84.2	---	---
27 Feb 72					
1	.0377	807.0	46.7	.0006	0.34
2	.0121	807.0	15.0	.0013	0.27
3	.0068	807.0	8.4	.0004	0.27
4	.0062	807.0	7.7	.0005	0.15
5	<u>.0243</u>	<u>807.0</u>	<u>30.1</u>	<u>.0007</u>	<u>0.80</u>
Total	.0871	807.0	107.9	.0035	1.83
29 Feb 72					
1	.0392	788.3	49.7	---	---
2	.0117	788.3	14.8	---	---
3	.0072	788.3	9.1	---	---
4	.0048	788.3	6.1	---	---
5	<u>.0277</u>	<u>788.3</u>	<u>35.1</u>	---	---
Total	.0906	788.3	114.9		
1 Mar 72 Bulk	.0494	1012.3	48.8	---	---
2 Mar 72					
1	.0082	775.9	10.6	.0004	0.12
2	.0037	775.9	4.8	.0000	0.08
3	.0020	775.9	2.6	.0003	0.04
4	.0025	775.9	3.2	.0002	0.04
5	<u>.0116</u>	<u>775.9</u>	<u>14.9</u>	<u>.0003</u>	<u>0.12</u>
Total	.0280	775.9	36.1	.0012	0.40

Table 5
(Continued)
DATA FROM 24-HOUR HI-VOLUME AMBIENT AIR SAMPLES

Sample	Particulate Weight (gm)	Volume Sampled (m ³)	Particulate Conc. (ug/m ³)	Mercury Conc. (ug/m ³)	Lead Conc. (ug/m ³)
3 Mar 72 Bulk	.0877	1097.3	79.9	---	---
4 Mar 72					
1	.0250	790.6	31.6	---	---
2	.0076	790.6	9.6	---	---
3	.0033	790.6	4.2	---	---
4	.0030	790.6	3.8	---	---
5	<u>.0171</u>	<u>790.6</u>	<u>21.6</u>	---	---
Total	.0560	790.6	70.8		
5 Mar 72 Bulk	.0988	1001.7	98.6	---	---
6 Mar 72					
1	.0312	809.9	38.5	.0027	0.48
2	.0118	809.9	14.6	.0007	0.37
3	.0074	809.9	9.1	.0005	0.22
4	.0039	809.9	4.8	.0005	0.22
5	<u>.0157</u>	<u>809.9</u>	<u>19.4</u>	<u>.0011</u>	<u>0.93</u>
Total	.0700	809.9	86.4	.0055	2.22
12 Mar 72					
1	.0264	801.4	32.9	.0004	0.29
2	.0117	801.4	14.6	.0003	0.26
3	.0055	801.4	6.9	.0003	0.11
4	.0055	801.4	6.9	.0003	0.14
5	<u>.0252</u>	<u>801.4</u>	<u>31.4</u>	<u>.0005</u>	<u>0.90</u>
Total	.0743	801.4	92.7	.0018	1.70
13 Mar 72 Bulk	.0765	1035.0	73.9	---	---
14 Mar 72					
1	.0205	788.9	26.0	.0126	0.13
2	.0060	788.9	7.6	.0000	0.13
3	.0029	788.9	3.7	.0051	0.09
4	.0029	788.9	3.7	.0001	0.09
5	<u>.0174</u>	<u>788.9</u>	<u>22.0</u>	<u>.0000</u>	<u>0.68</u>
Total	.0497	788.9	63.0	.0178	1.12

Table 5
(Continued)

DATA FROM 24-HOUR HI-VOLUME AMBIENT AIR SAMPLES

Sample	Particulate Weight (g)	Volume Sampled (m ³)	Particulate Conc. (ug/m ³)	Mercury Conc. (ug/m ³)	Lead Conc. (ug/m ³)
26 Mar 72					
1	.0162	829.7	19.5	---	---
2	.0078	829.7	9.4	---	---
3	.0027	829.7	3.2	---	---
4	.0037	829.7	4.4	---	---
5	<u>.0212</u>	<u>829.7</u>	<u>25.6</u>	---	---
Total	.0516	829.7	62.2		
27 Mar 72					
Bulk	.0597	991.1	60.2	---	---
28 Mar 72					
1	.0240	812.7	29.5	---	---
2	.0096	812.7	11.8	---	---
3	.0042	812.7	5.2	---	---
4	.0028	812.7	3.4	---	---
5	<u>.0170</u>	<u>812.7</u>	<u>20.9</u>	---	---
Total	.0576	812.7	70.9		
29 Mar 72					
Bulk	.0774	966.3	80.1	---	---
30 Mar 72					
1	.0294	852.4	34.5	---	---
2	.0079	852.4	9.3	---	---
3	.0037	852.4	4.3	---	---
4	.0010	852.4	1.2	---	---
5	<u>.0220</u>	<u>852.4</u>	<u>25.8</u>	---	---
Total	.0640	852.4	75.1		
1 Apr 72					
1	.0147	829.7	17.7	.0000	0.16
2	.0066	829.7	7.9	.0000	0.12
3	.0030	829.7	3.6	.0000	0.08
4	.0025	829.7	3.0	.0001	0.08
5	<u>.0140</u>	<u>829.7</u>	<u>16.9</u>	<u>.0000</u>	<u>0.42</u>
Total	.0408	829.7	49.2	.0001	0.86
3 Apr 72					
Bulk	.0745	1009.4	73.8	---	---

Appendix B

EquipmentSampler

Sampler Head. Since the human respiratory system removes particles from the air aerodynamically, a sampler head was chosen which operated on the same principle. An Anderson high-volume sampler head manufactured by 2000 Inc. was selected for this study (Fig. 6). Particulates were separated into four size groups by the impaction method, greater than 7.0, 3.3 to 7.0, 2.0 to 3.3, and 1.1 to 2.0 microns. A backup filter was used to collect those particles which passed the final stage of the head. Collection efficiencies of the four stages of the sampler head are shown in Fig. 7.

The rate at which a particle falls in the atmosphere depends on the weight and the aerodynamic drag of the particle. The "equivalent aerodynamic diameter" is defined as the diameter of a sphere with a density of 1 gram/cm^3 having the same falling velocity as the particle in question. All particle sizes in this thesis, unless otherwise stated, are equivalent aerodynamic diameters.

Jet Plates. The sampling head holds five aluminum plates which range from 0.635 to 0.127 cm in thickness (Fig. 8). Each plate contains 300 orifices, the diameters of which decrease in succeeding stages of the head.

Gasket-Spacer. The jet plates are separated by five

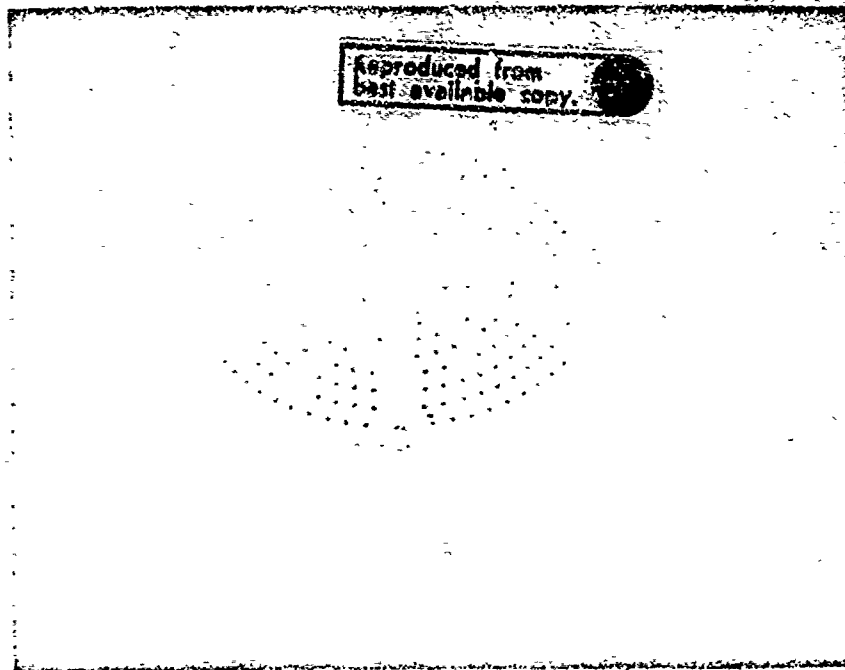


Fig. 6. Assembled Sampler Head

0.635-cm thick neoprene gaskets. In addition to separating the plates they hold the collection paper in place on the lower plate, and serve as an airtight seal between the plates.

Collection Paper. The collection paper is composed of type "A" non-hygroscopic fiberglas. The sheets of paper have been specially cut and perforated to fit each stage of the head.

Interface Adapter Plate. The plates, gaskets, and collection paper were mounted on the interface adapter plate shown in Fig. 8. The adapter consists of a center shoulder bolt and four dowel pins press fitted into the mounting plate, and serves as a structural frame for the sampler head. When all components were in place a speedball handle was tightened on the shoulder bolt to seal the unit.

As the airstream passes through the orifices of the

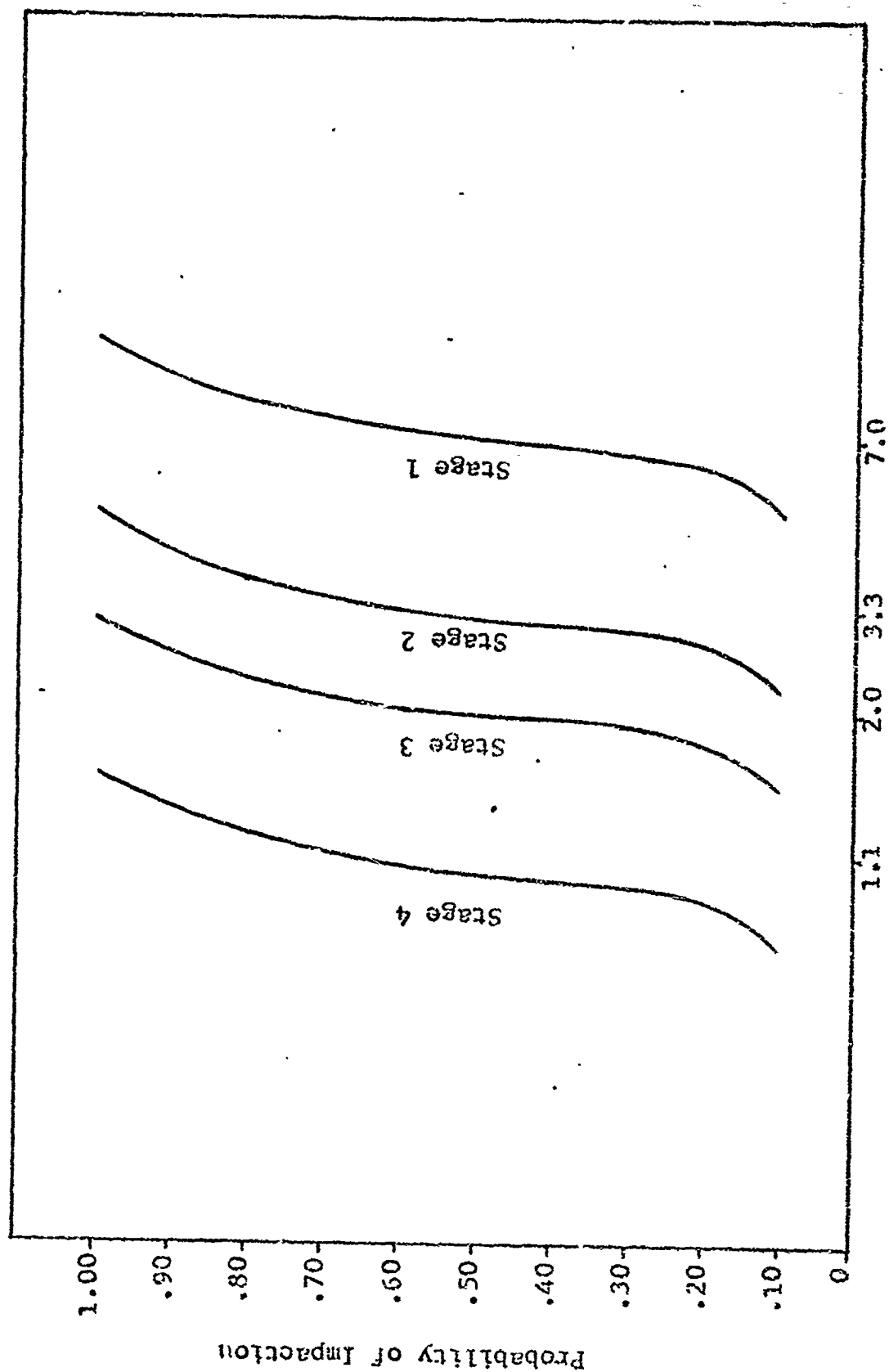


Fig. 7. Collection Efficiency of Sampler Head Stages

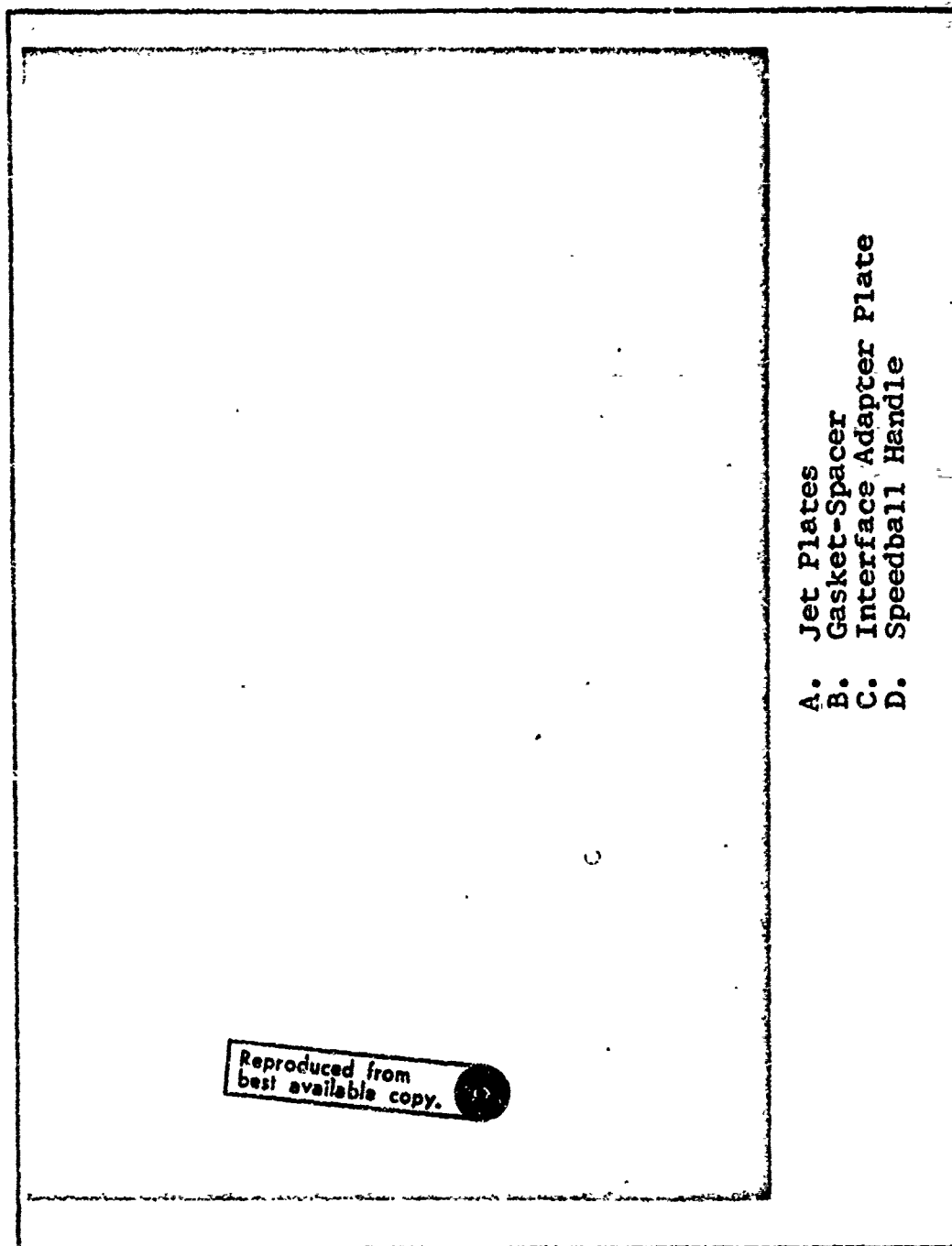


Fig. 8. Components of Sampler Head

upper plate, it is directed vertically downward. Thus the particles in the airstream have a certain amount of inertia, depending on the velocity and mass of the particle, in that direction, and tend to resist any change in velocity. Since the jet orifices in the lower plate are not directly below those of the upper plate, the airstream must change directions as it leaves the upper orifice. If the inertia of the particles is great enough to overcome the aerodynamic drag of the airstream, they will impact on the collection paper directly below the upper orifice. As the velocity of the airstream increases through the smaller orifices of each succeeding stages, the smaller particles gain enough inertia to escape the airstream and impact on the collection paper.

Adapter. An adapter plate (Fig. 9) was constructed to attach the sampler head to a standard 20.32 by 25.40-cm rectangular attachment of a Staplex hi-volume sampler. A 0.158-cm thick cork gasket was cemented to the top and bottom surfaces of the adapter to ensure that no air entered the sampler below the head. The sampler head was mounted on the top surface, and the bottom surface was used to hold the backup filter securely on the 20.32 by 25.40 cm mount.

Staplex Sampler. A Staplex hi-volume air sampler was used to pull air through the sampler head. It was equipped with a 20.32 by 25.4-cm rectangular attachment for mounting the backup filter and sampler head. The assembled configuration is shown in Fig. 10.

Manometer. A manometer was used to accurately set the sampler for an equivalent pressure drop corresponding to a

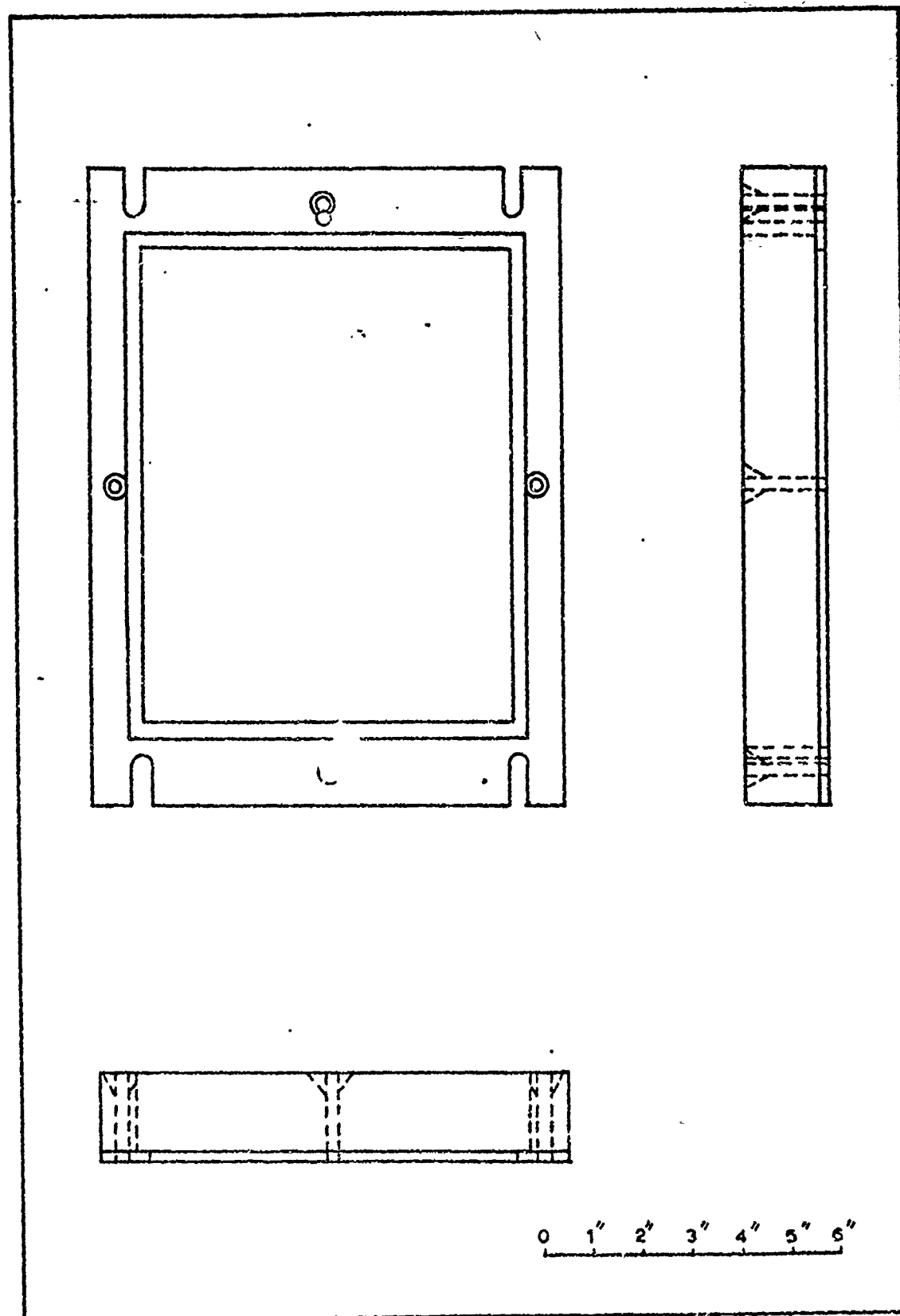


Fig. 9. Adapter Plate

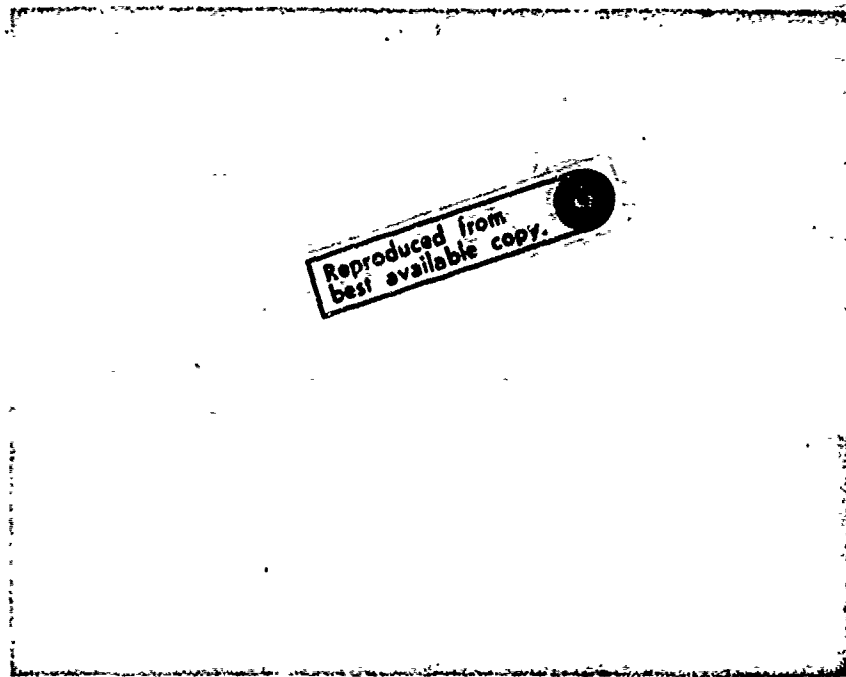


Fig. 10. Assembled Sampler

flow rate of 0.566 cmm. The scale on the manometer was calibrated with red gage oil, specific gravity .826, to correspond with inches of water. The sampler head was calibrated at the factory to determine the equivalent pressure drop for various elevations, and a curve giving this information was included with the head.

Variable Voltage Transformer. The Staplex sampler was connected to a variable voltage transformer to properly adjust the flow rate of the sampler. The transformer was connected to a 115 volt alternating current outlet. Approximately 55 volts were required to operate the sampler at the proper flow rate.

Shelter. The assembled sampling unit was installed in a shelter as shown in Figs. 11 and 12. The shelter was manufactured locally, and the dimensions are shown in Fig. 11.

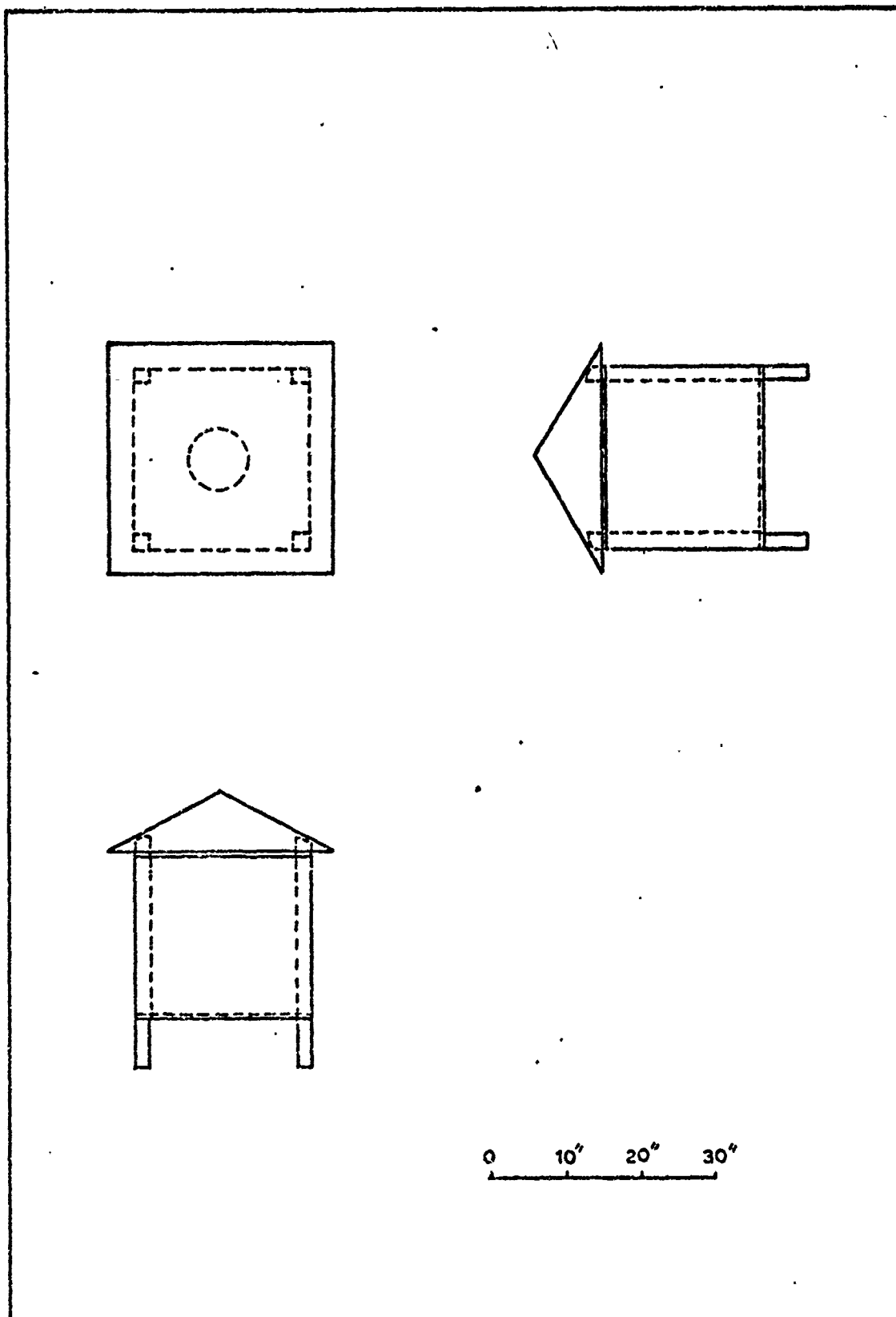


Fig. 11. Sampling Shelter

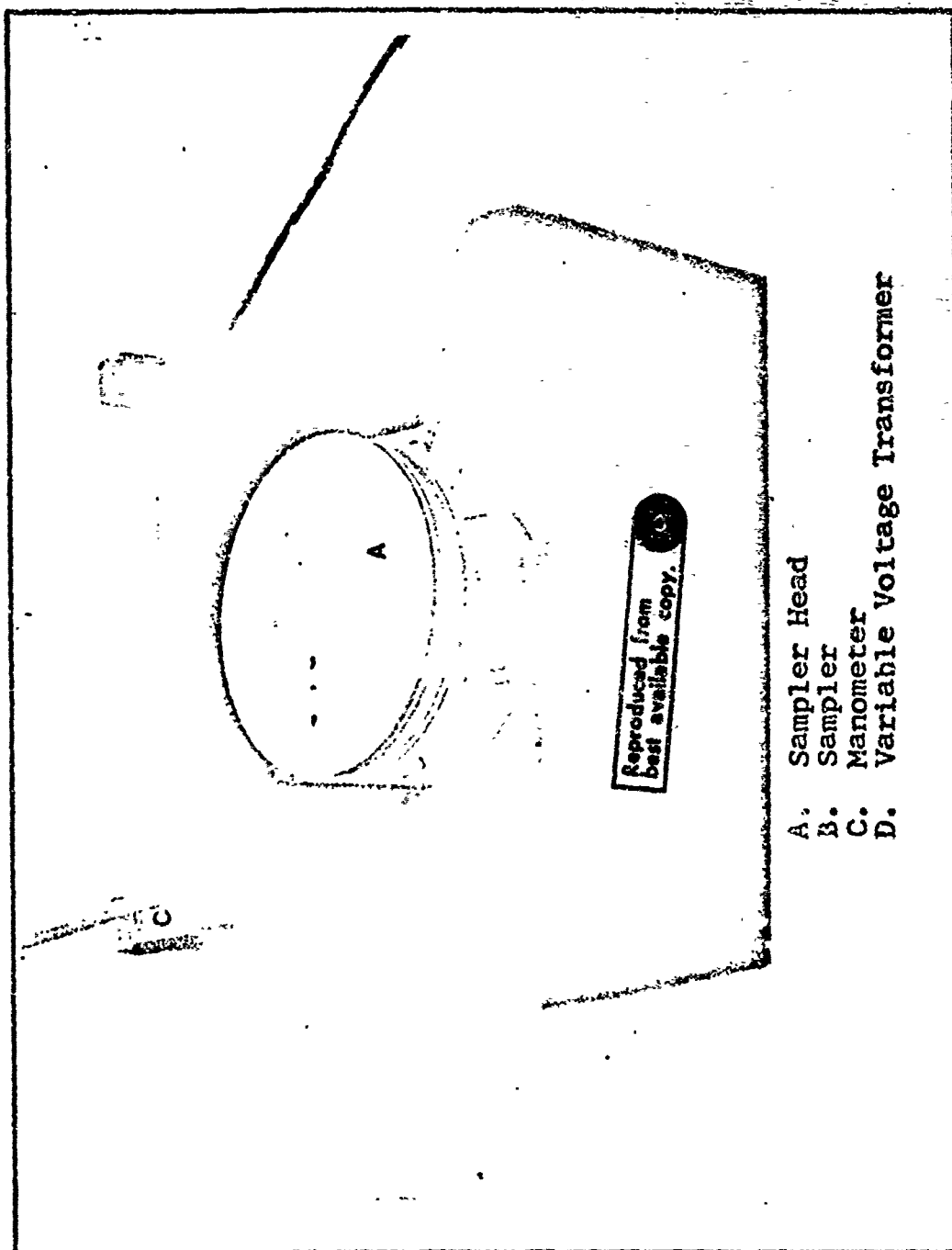


Fig. 12. Air Sampler Installed in Shelter

Scale. A Right-A-Weigh balance manufactured by Wm. Ainsworth & Sons, Inc. was used to determine the weights of collection papers and filters before and after sampling. The scale had a 200 gram capacity and a sensitivity of 1/10 milligram.

Glassware

Several items of glassware were used in the chemical analysis of the particulates. The absorption cell used in the mercury analysis was the only locally manufactured piece. It was constructed of borosilicate glass tubing, 25-mm o.d. by 150 mm. The ends were ground perpendicular to the longitudinal axis, and quartz windows 25 mm in diameter and 2 mm thick were cemented on each end. Gas inlet and outlet ports were installed approximately 20 mm from each end. The absorption cell is shown schematically in Fig. 2 mounted in the atomic absorption unit.

Other standard items of glassware used were:

1. 1000 ml volumetric flasks
2. 100 ml volumetric flasks
3. 25 ml volumetric flasks
4. 250 ml erlenmeyer flasks
5. 1000 ml filtration flask
6. 125 ml filtration flasks
7. Buchner funnels, 105 mm inside diameter
8. Buchner funnels, 50 mm inside diameter
9. 50 ml volumetric cylinders
10. funnels, 65 mm inside diameter

11. funnels, 105 mm inside diameter
12. 100 ml beakers
13. plastic wash bottles

Atomic Absorption Spectrophotometer

A Perkin-Elmer Model 403 atomic absorption spectrophotometer was selected to conduct the trace element analysis. A Model 403 burner control was used for flame absorption in the lead analysis, and a flameless technique described in Chapter II was used in the mercury analysis.

Computer

A CDC 6600 computer located on Wright-Patterson AFB was used to compute and plot the least-squares curve fits of all calibration curves in the atomic absorption work, and to conduct the stochastic analysis of particulate concentrations described in Chapter III.

Appendix C

Flow Diagram for
Stochastic Analysis Computer Program

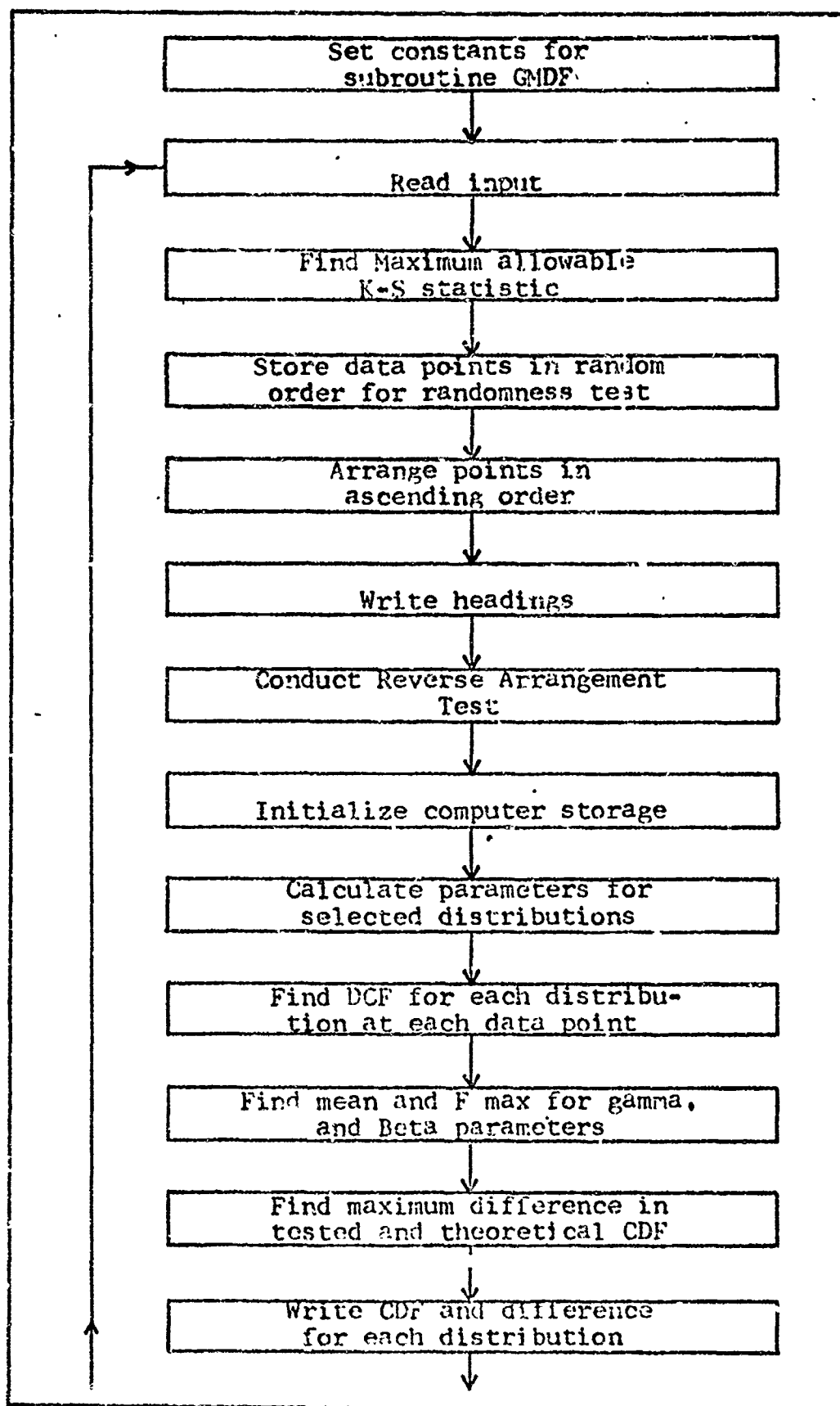


Fig. 13. Computer Flow Diagram (Ref. 20)

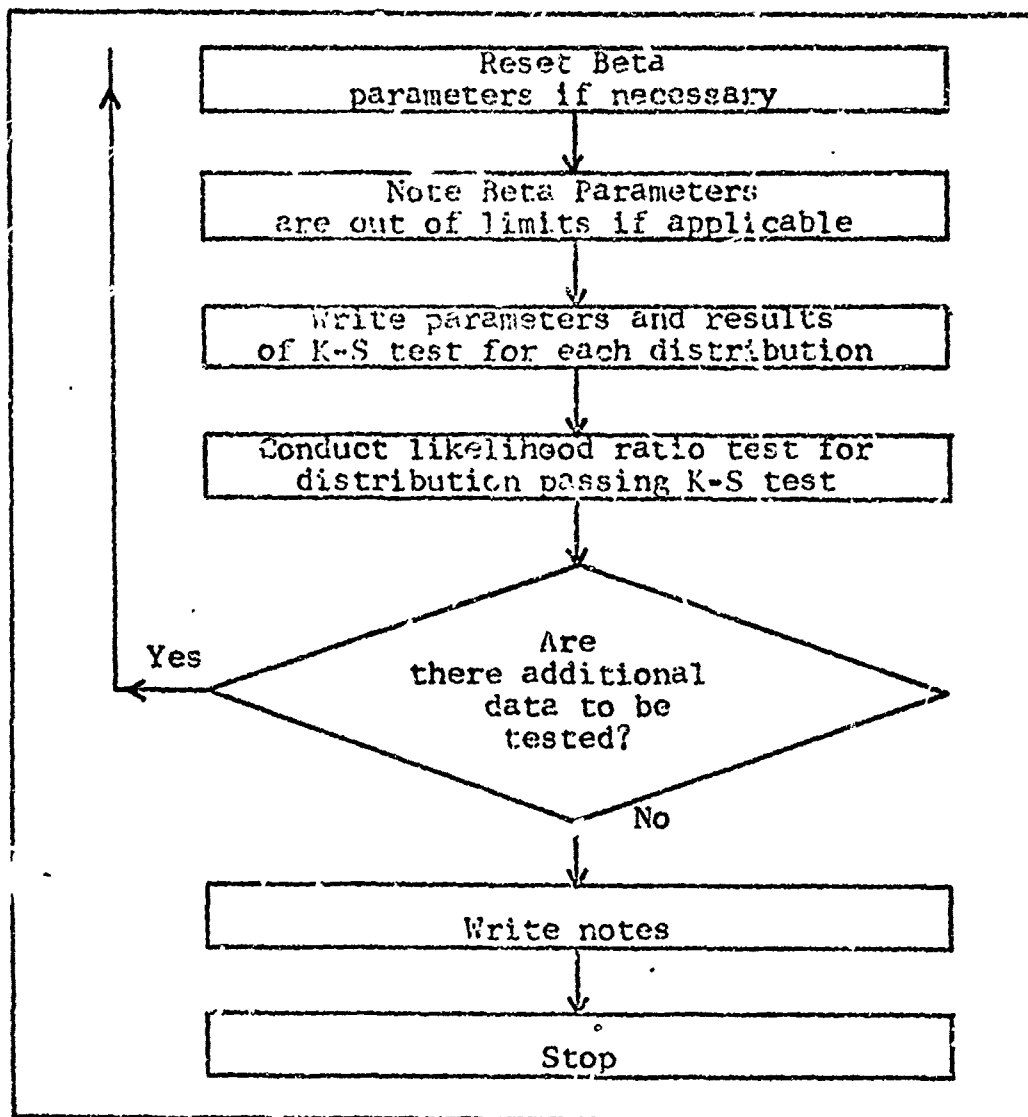


Fig. 13. Computer Flow Diagram (Continued)

Appendix D

Mathematical Expressions of
Probability Density Functions

The probability density functions use in the computer program are shown in this appendix and are described in terms of the parameters of each function.

1. Smallest Extreme Value:

$$F(X) = 1 - \exp(-\exp((X - C)/M)) \quad (10)$$

2. Largest Extreme Value:

$$F(X) = \exp(-\exp(-(X - C)/M)) \quad (11)$$

3. Uniform:

$$F(X) = (X - A)/(B - A) \quad (12)$$

4. Exponential:

$$F(X) = 1 - \exp(-A * X) \quad (13)$$

5. Lognormal:

$$F(X) = 1/\sqrt{2\pi I} \int_0^X \exp(-Z^2/2) \quad (14)$$

$$\text{where } Z = (\log(X) - C)/M \quad (15)$$

6. Normal:

$$F(X) = 1/\sqrt{2\pi I} \int_0^X \exp(-Z^2/2) \quad (16)$$

$$\text{where } Z = (X - U)/SD \quad (17)$$

7. Gamma:

$$F(X) = 1/\text{GAMMA}(A) * M^{**}A^{*}$$

$$\text{INTEGRAL } ((X-C)**(A-1)*\text{EXP}(-(X-C)/M) \quad (18)$$

8. Weibull:

$$F(X) = 1-\text{EXP}(-((X-C)/M)**A) \quad (19)$$

9. Beta:

$$F(X) = \text{GAMMA}(A+B)/\text{GAMMA}(A)*\text{GAMMA}(B)*M^{**}(A+B+1)*$$

$$\text{INTEGRAL } ((X-C)**(A-1)*(C+M-X)**B-1) \quad (20)$$

Where parameters are estimated from moments

10. Beta is the same as Beta, with C estimated as X(1),
and M is estimated as X(N)-X(1)

Symbols used in the above equations are:

Mean	= U
Standard Deviation	= SD
Shape Parameter (A)	= A
Shape Parameter (B)	= B
Scale Parameter	= M
Location Parameter	= C
PI	= 3.1416...
Multiply	= *
Raise to a Power	= **

Appendix E

Probability of a Stated Level of
Total Particulate Concentration

Since the Lognormal density function describes the data on total particulate concentration, Eq (1) holds true.

$$F(X) = \int_0^x \frac{1}{\sigma x \sqrt{2\pi}} e^{-\frac{1}{2} \left(\frac{\ln x - u}{\sigma} \right)^2} dx \quad (21)$$

where

u = mean of \ln of x and is the basic scale parameter of the Lognormal distribution

and

σ = standard deviation of $\ln x$

Thus, given any level of particulate concentration and the values in Table IV, Eq (1) can be evaluated by using the transformation

$$z = \frac{\ln x - u}{\sigma} \quad (22)$$

and standard normal distribution tables.

Example: What is the probability that the total particulate concentration on WPAFB will exceed 120 ug/m^3 based on the results of this study?

Step 1. Calculate z

$$z = \frac{\ln 120 - \ln 85.137}{\ln 32.375}$$

$$z = 0.09869$$

Entering standard normal distribution tables we see that 83.82% of the area is below $z = .09869$. Therefore, the probability that the concentration will exceed 120 ug/m^3 is $1 - 0.8382 = .1618$.

Vita

Dennis L. Brown was born on June 15, 1945 in Detroit Lakes, Minnesota. After attending Detroit Lakes High School, Detroit Lakes, Minnesota, he entered North Dakota State University, Fargo, North Dakota in September 1963. He graduated with a Bachelor of Science degree in civil engineering and received his commission as a Second Lieutenant through the ROTC program in May, 1967. He served as Chief of Utilities for the 4751st Air Defense Squadron, Eglin Auxiliary Field No. 9, Florida, until entering the Graduate Space Facilities program at the Air Force Institute of Technology in June, 1970.

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